NS102 Lecture 17

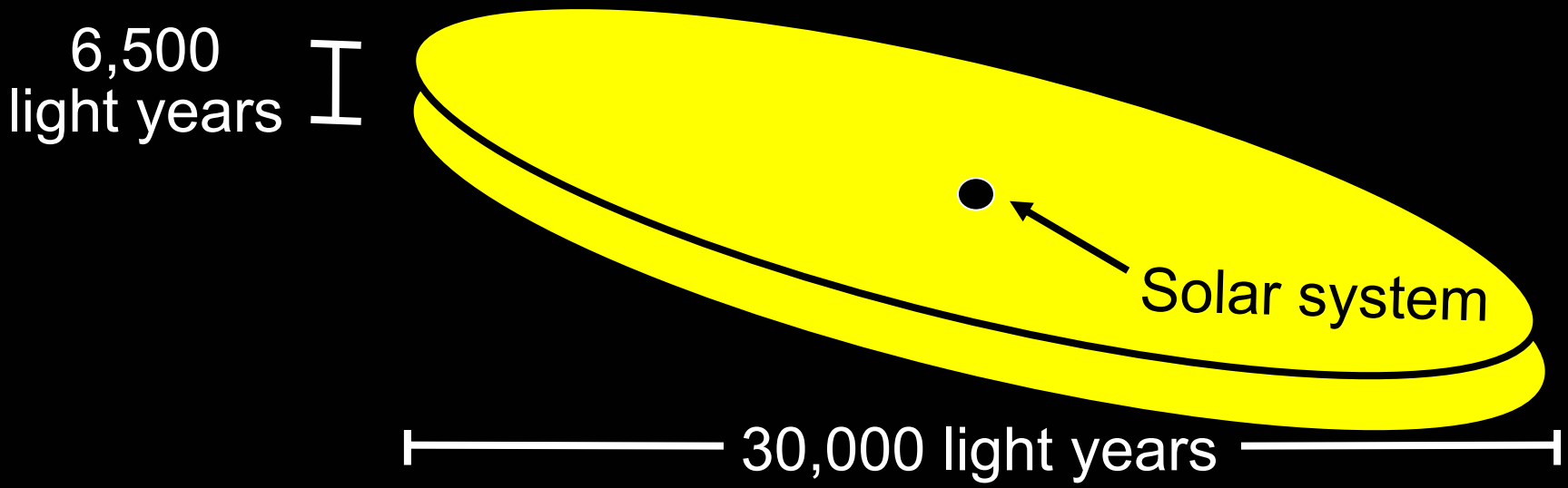
Open: *Naked Einstein* - Naked to the World
Close: *Blast Off* - Weezer

GnatSigh News
(all the news that fits)

- Website http://home.fnal.gov/~rocky/NS102/
- Exam #2 to be returned after class
  - Average = 60.1/80 (75%) [1st exam 63.1/75 = 84%]
  - Highest normalized score counts for 30% of final grade
- Please complete course evaluation at end of class
- Final Exam
  - 10:30-12:30 Thursday 9 June
  - Help sessions:
    - TAs: next Tues & Wed (check website for times)
    - Instructor: 10 am Thursday 2 June
    - Keywords will be posted on website

A view of the universe, circa 1905

1) Arrangement:



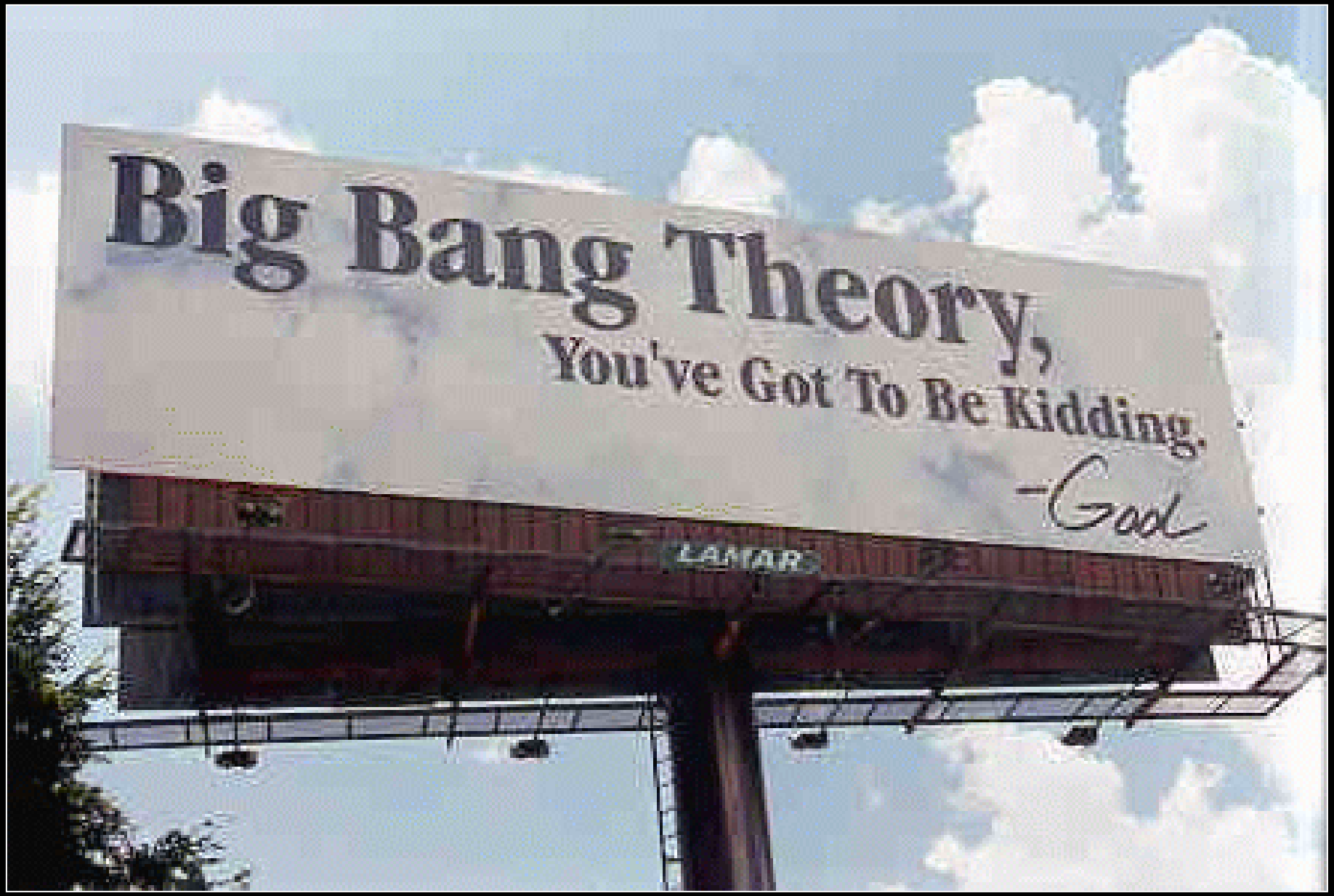
2) Composition: Starz' in the 'hood

3) Static (unchanging in time)

4) Origin???

5) Space and time are absolute

The Big Bang

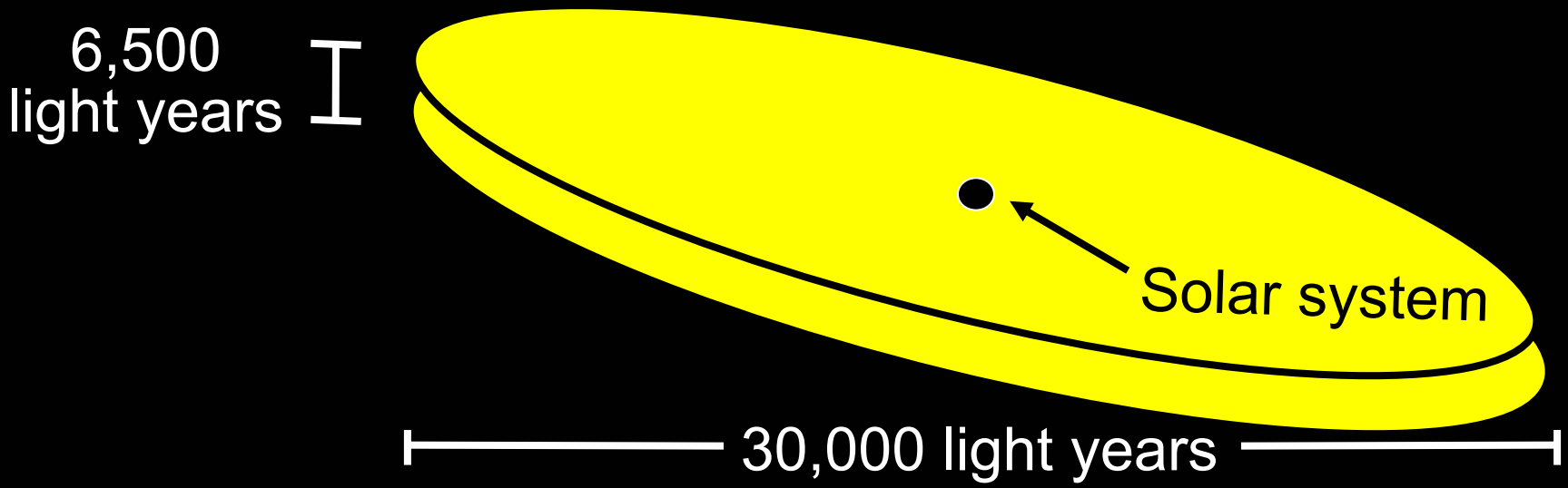


Aleksandr Aleksandrovich Friedmann
(1888-1925)

Georges-Henri Lemaître
(1894-1966)

A view of the universe, circa 1905

1) Arrangement:



2) Composition: Starz' in the 'hood

3) Static (unchanging in time)

4) Origin???

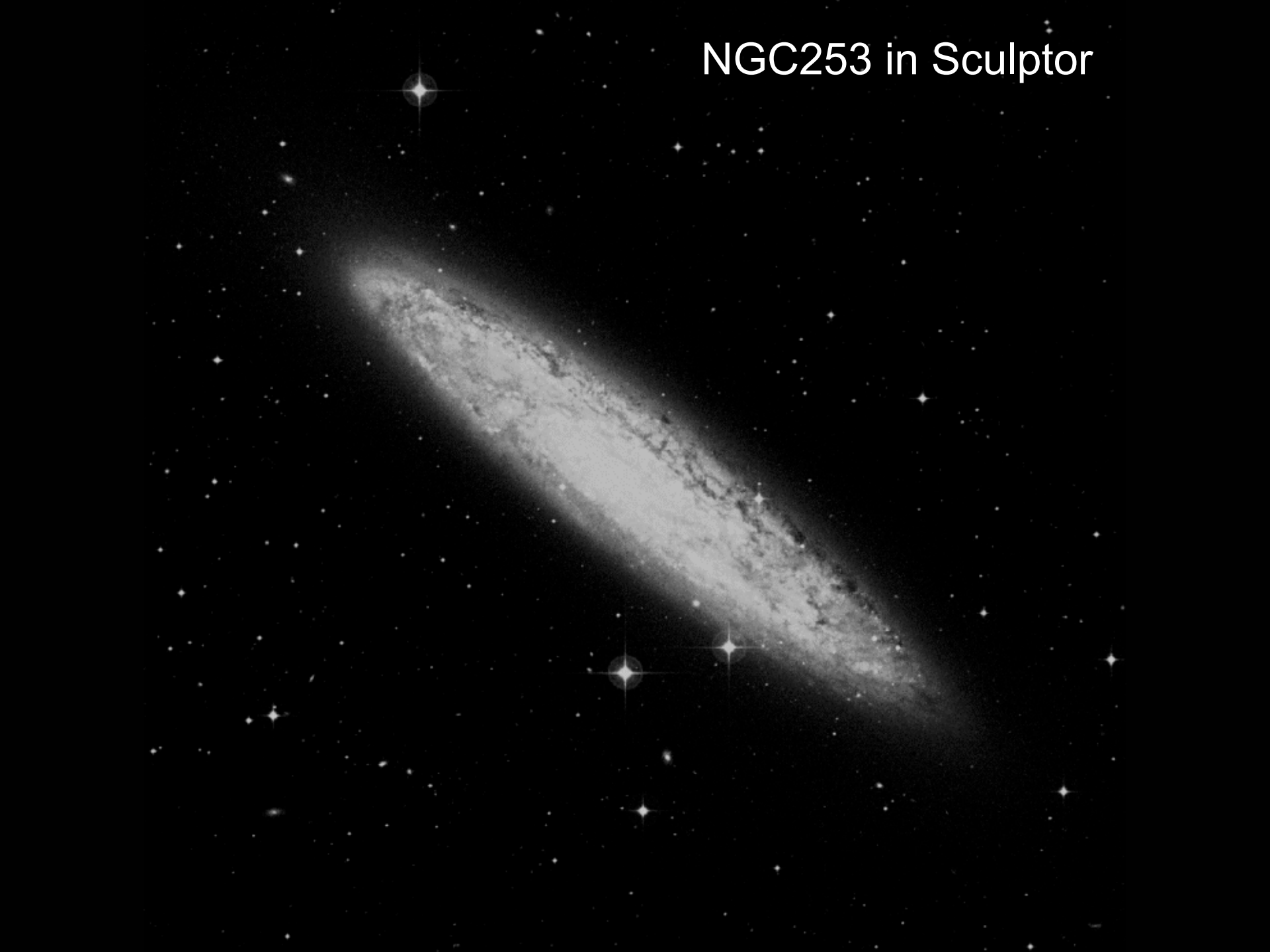
5) Space and time are absolute

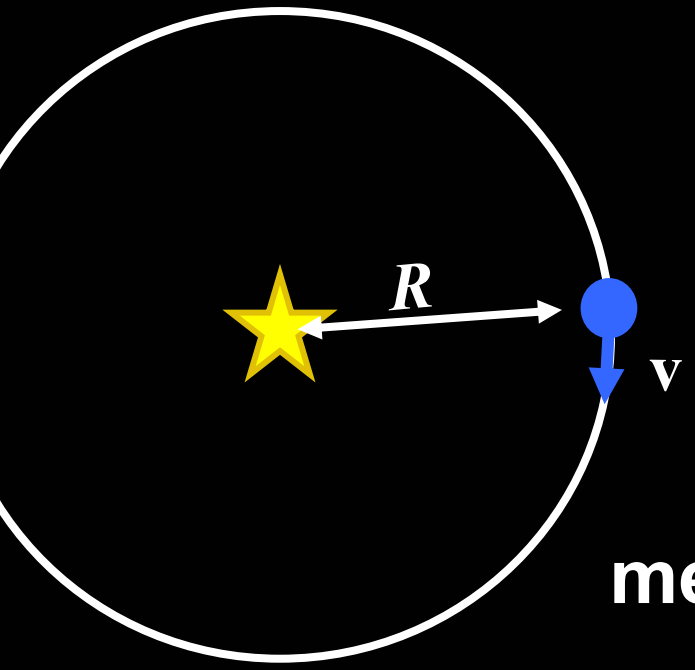
The visible universe

M63

Galaxies

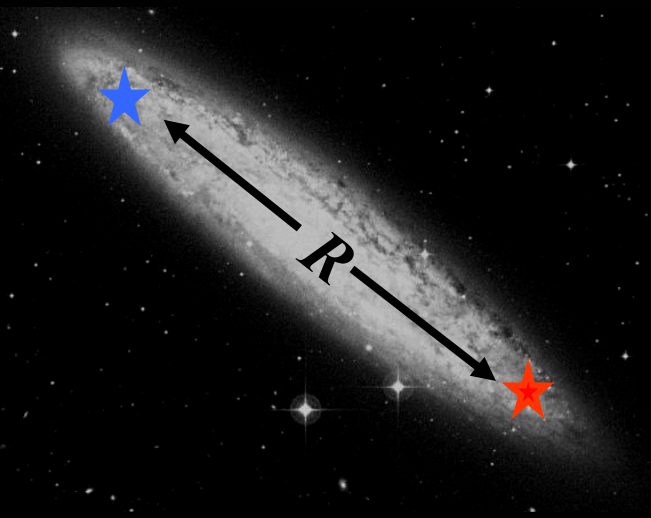
Most of the universe is dark!


NGC253 in Sculptor



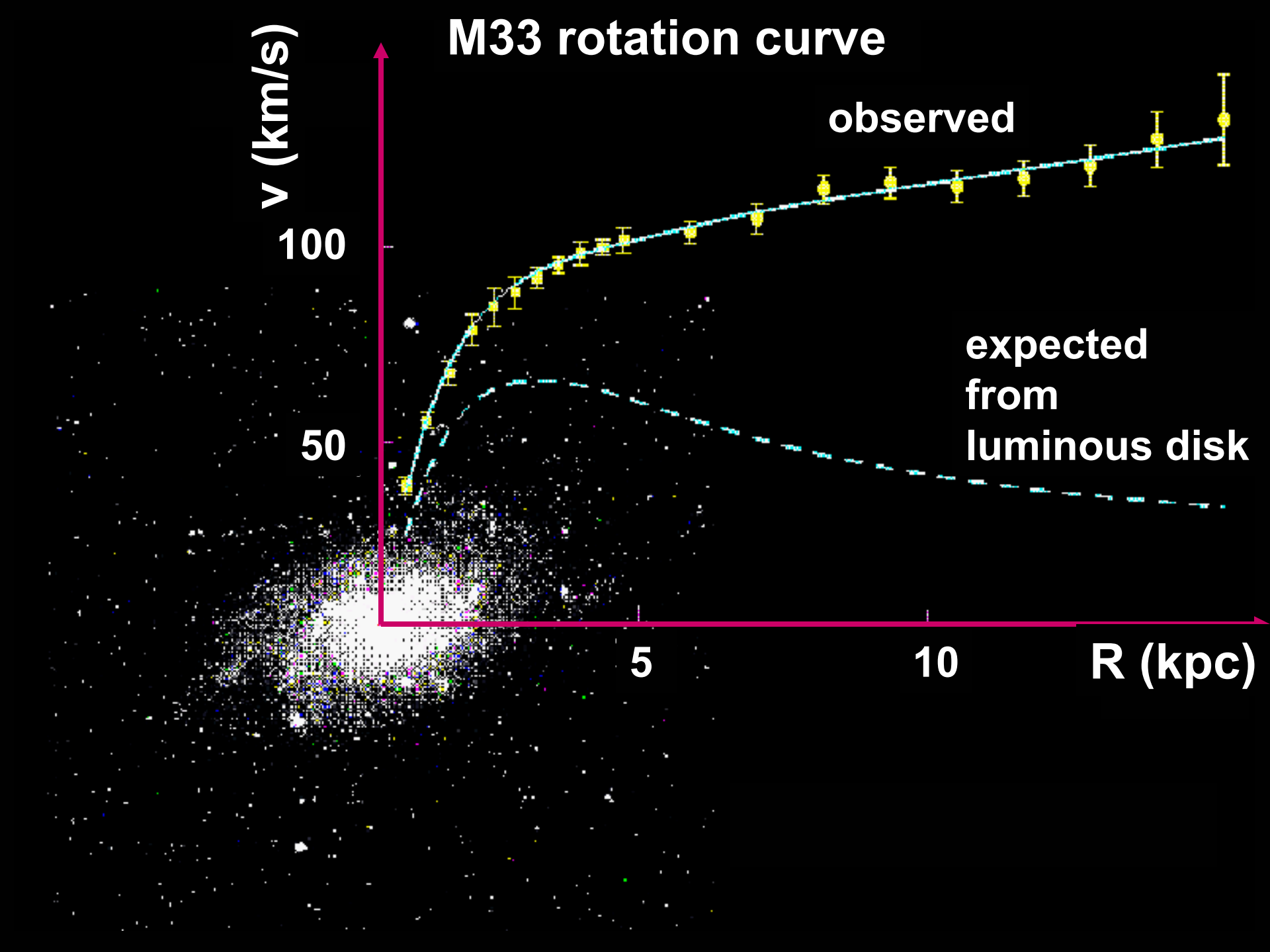
$$\frac{v^2}{R} = \frac{GM_{SUN}}{R^2}$$

measure v & R ⇒ M_{SUN}

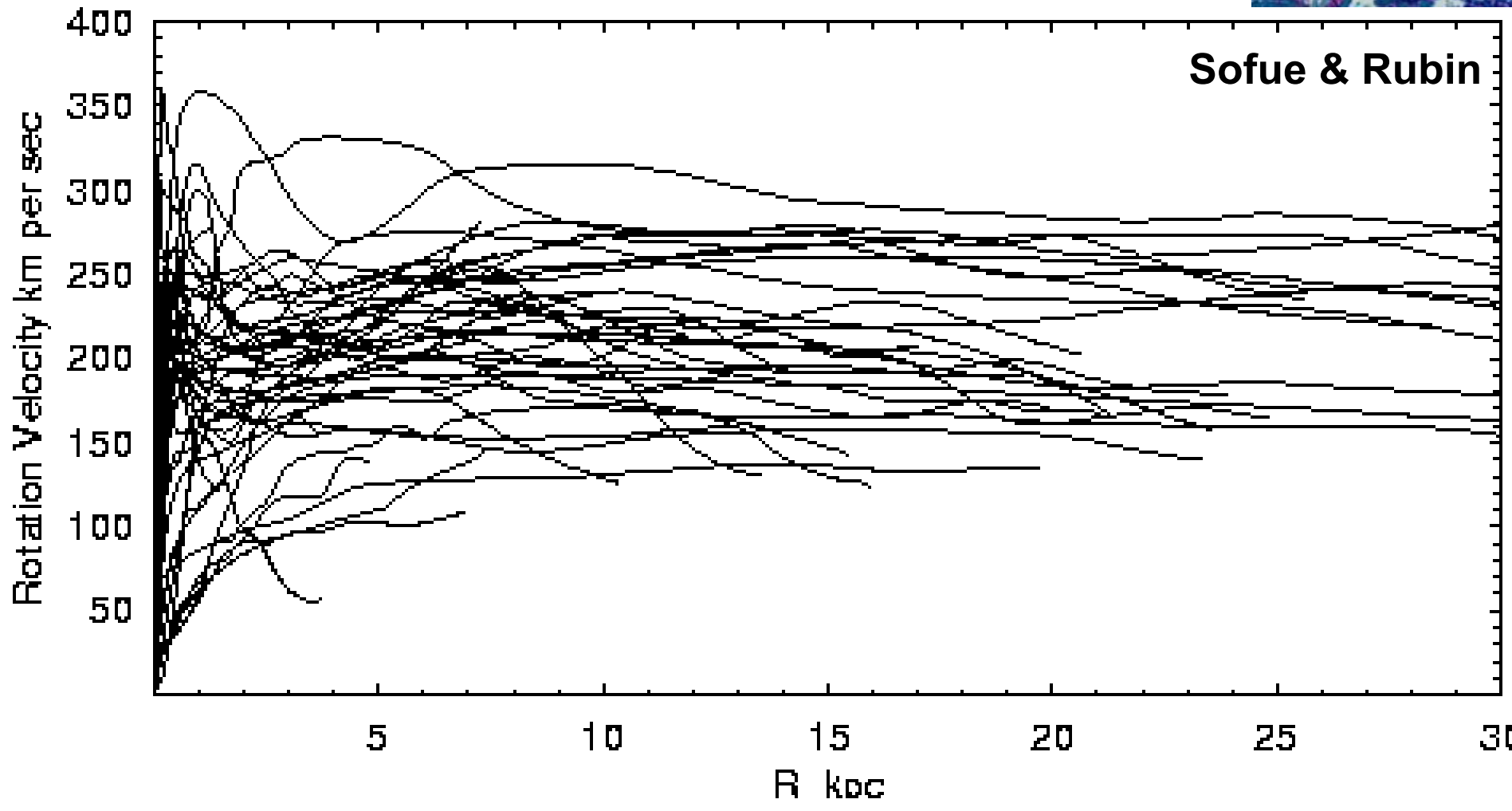


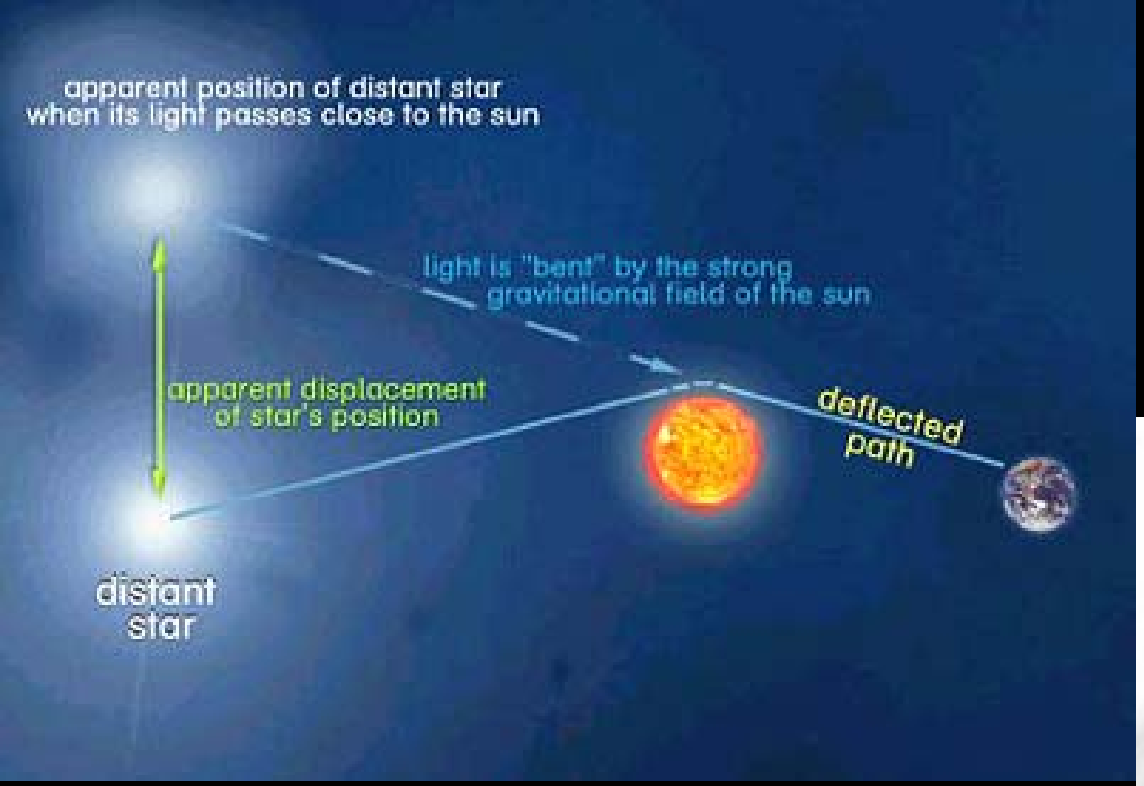
$$\frac{v^2}{R} = \frac{GM_{GALAXY}}{R^2}$$

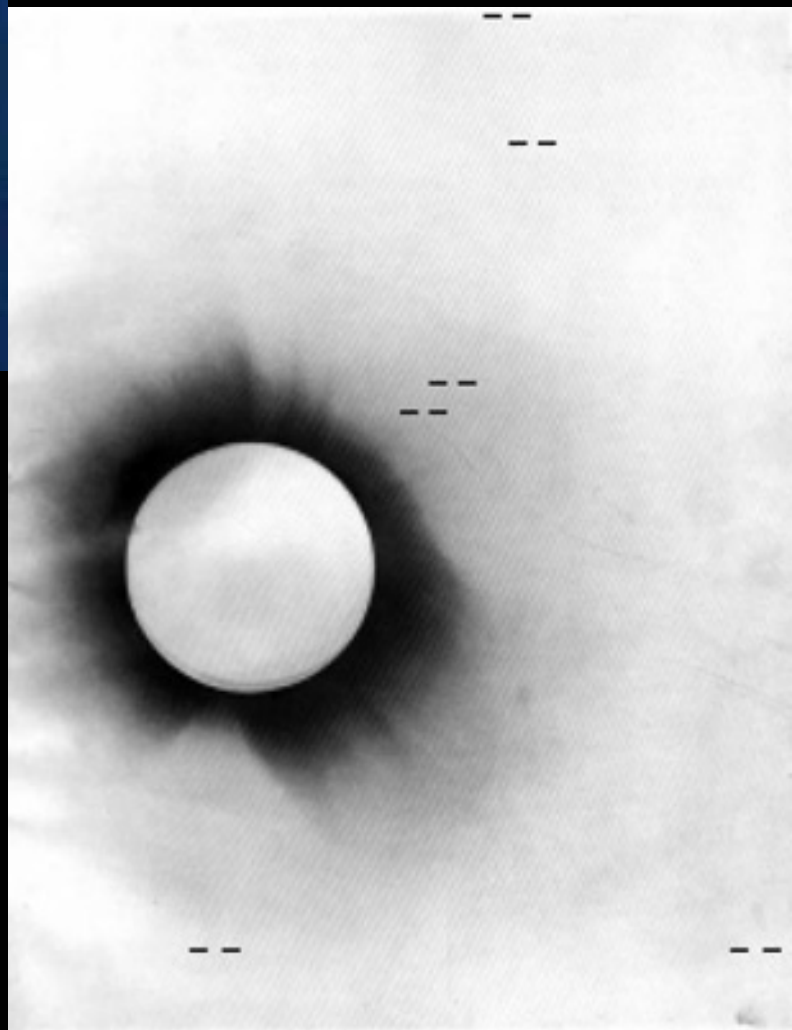
measure v & R ⇒ M_{GALAXY}


M33 rotation curve
v (km/s)
100
50
observed
expected
from
luminous disk
5
10
R (kpc)

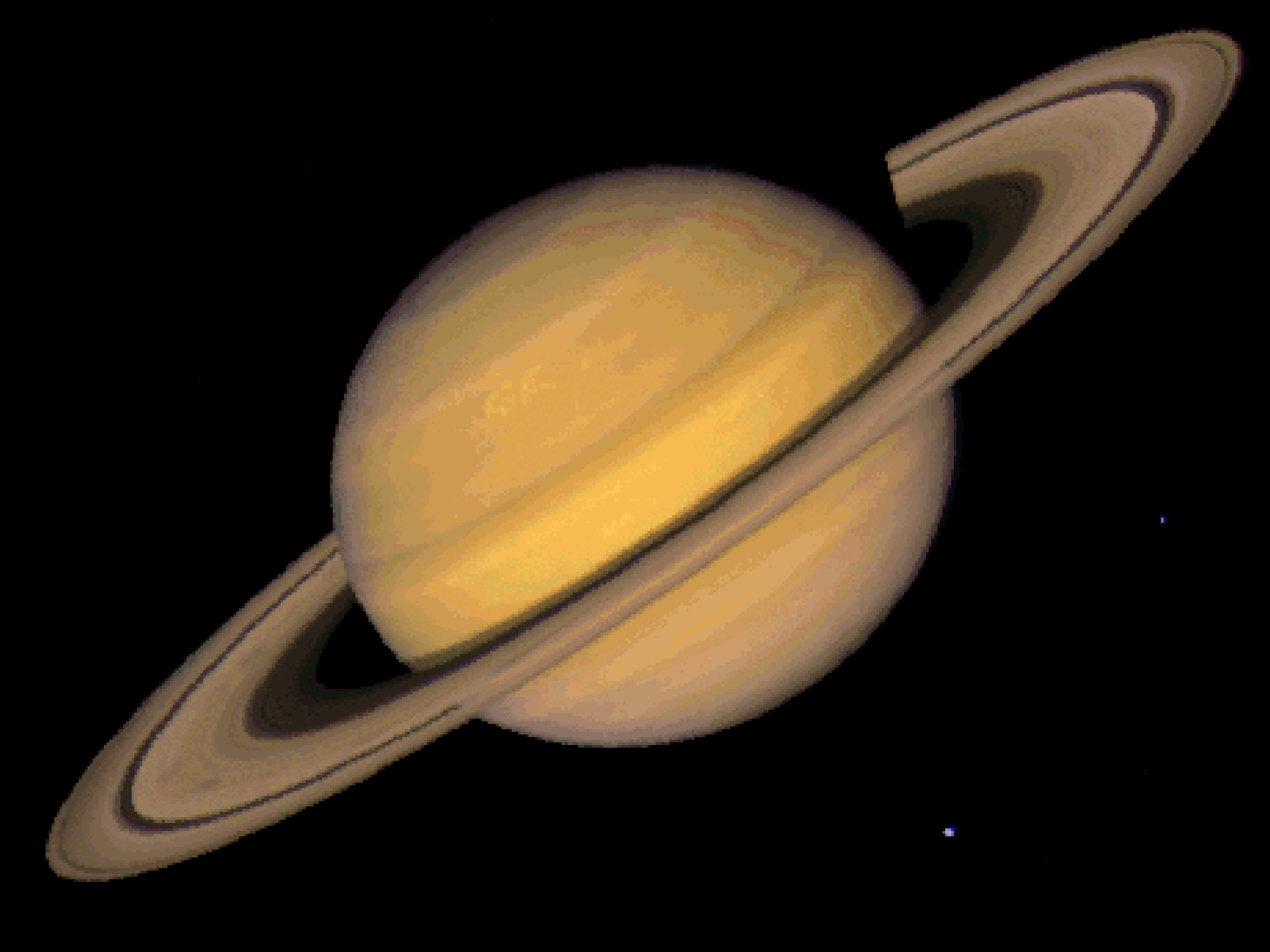
Rotation curves

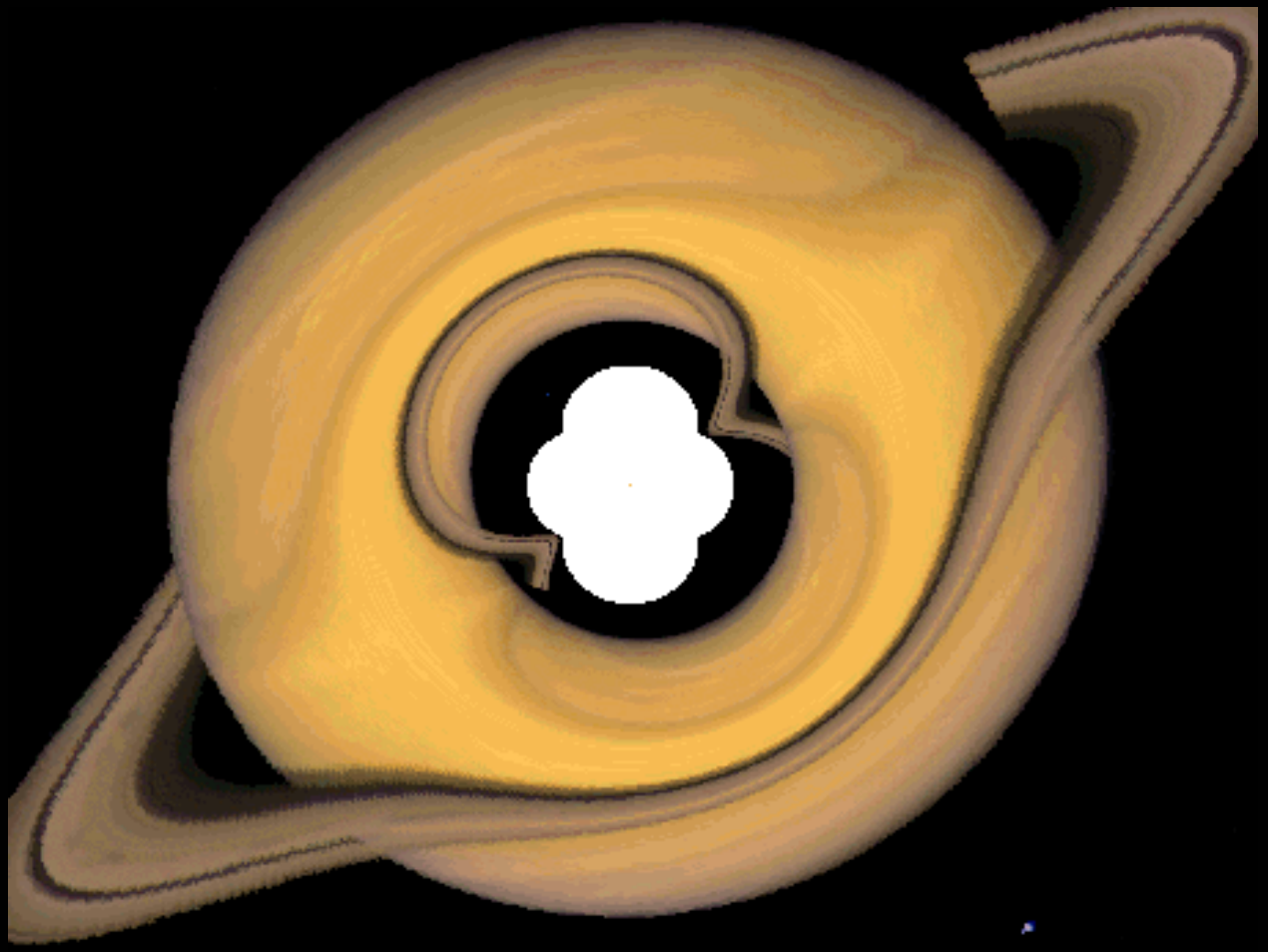






1919 Eclipse Expedition





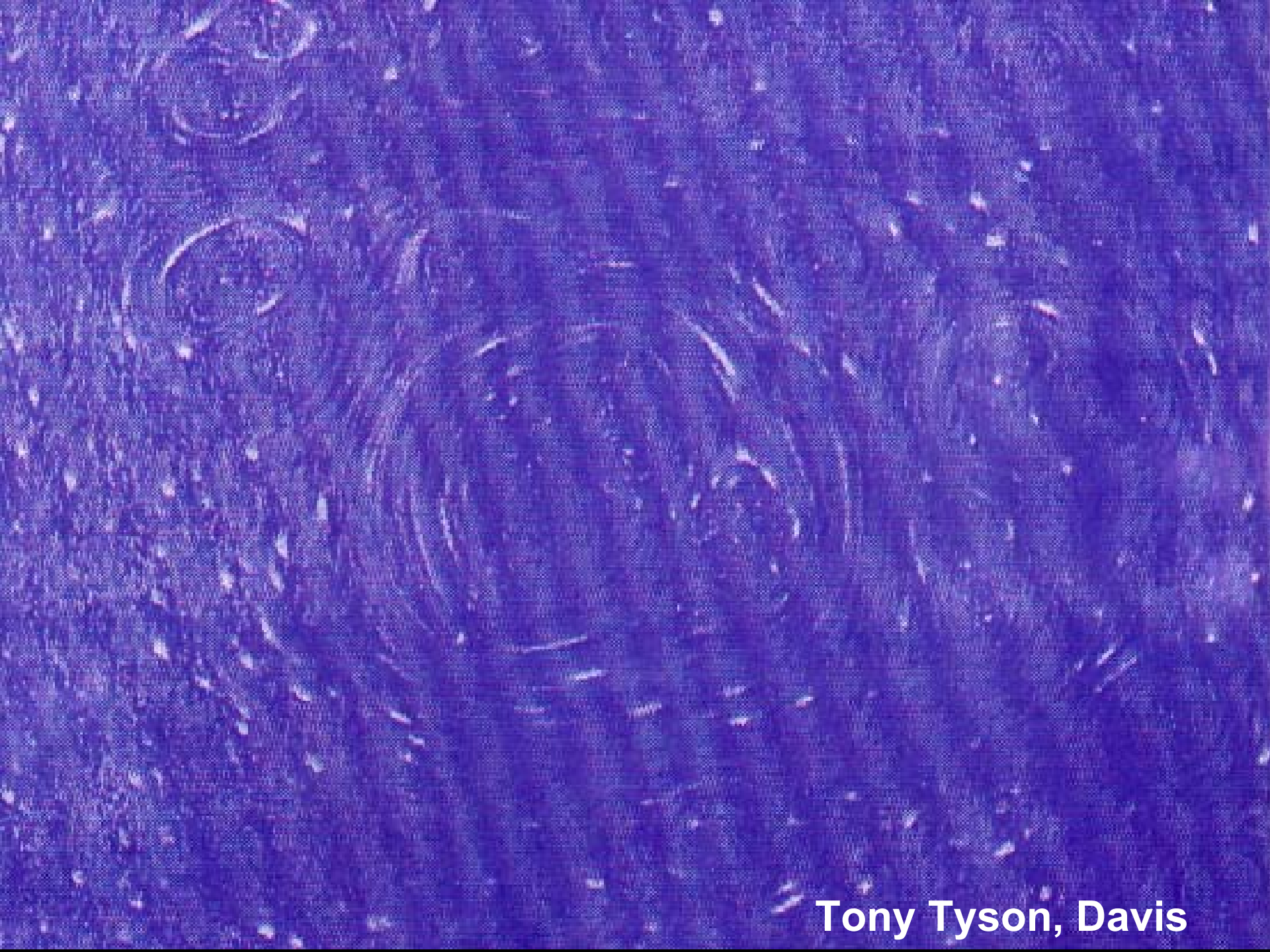
Gravitational Lensing

Gravitational Lens in Abell 2218

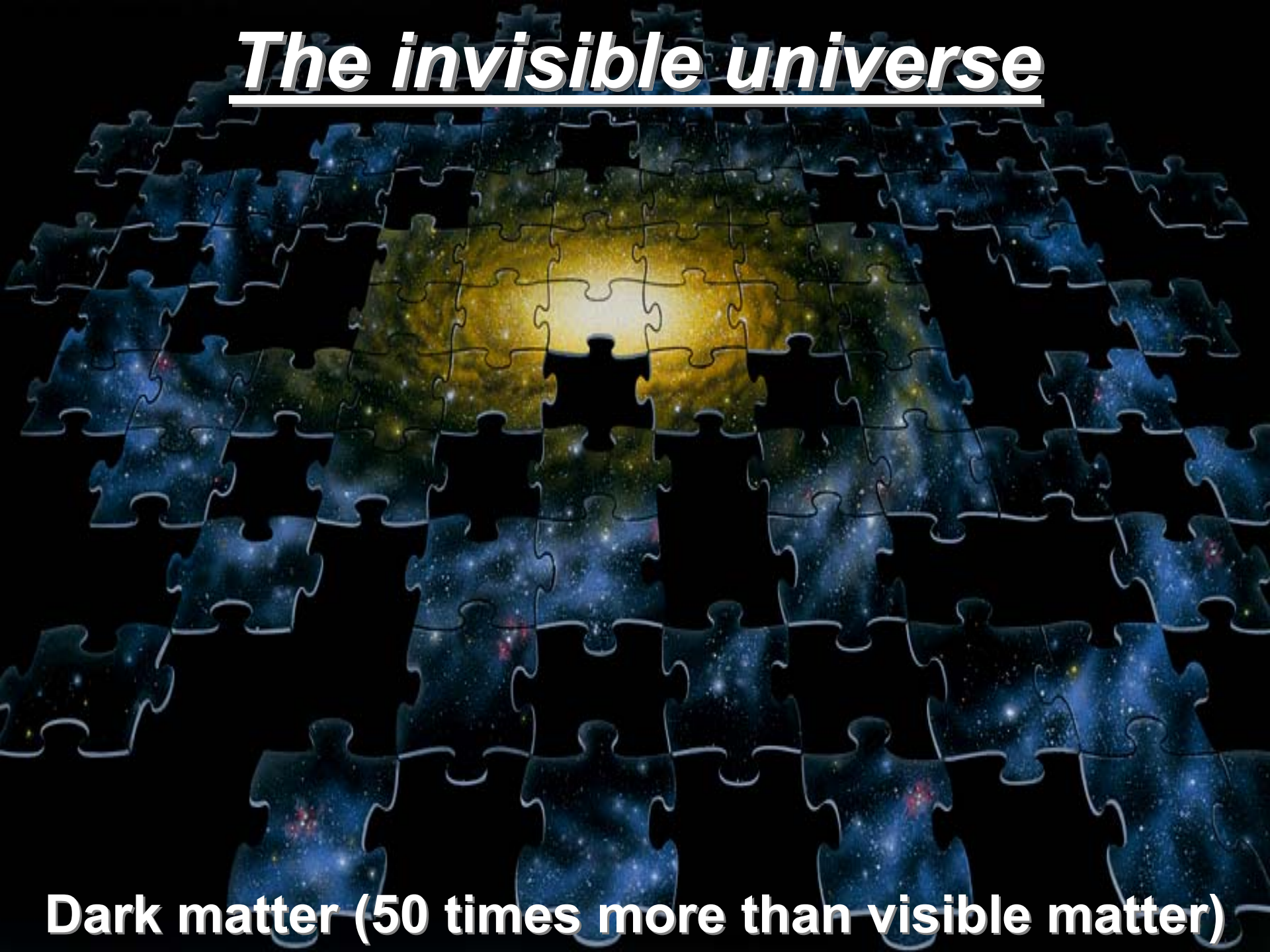
HST • WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

Gravitational Lens
Galaxy Cluster 0024+1654
Hubble Space Telescope • WFPC2

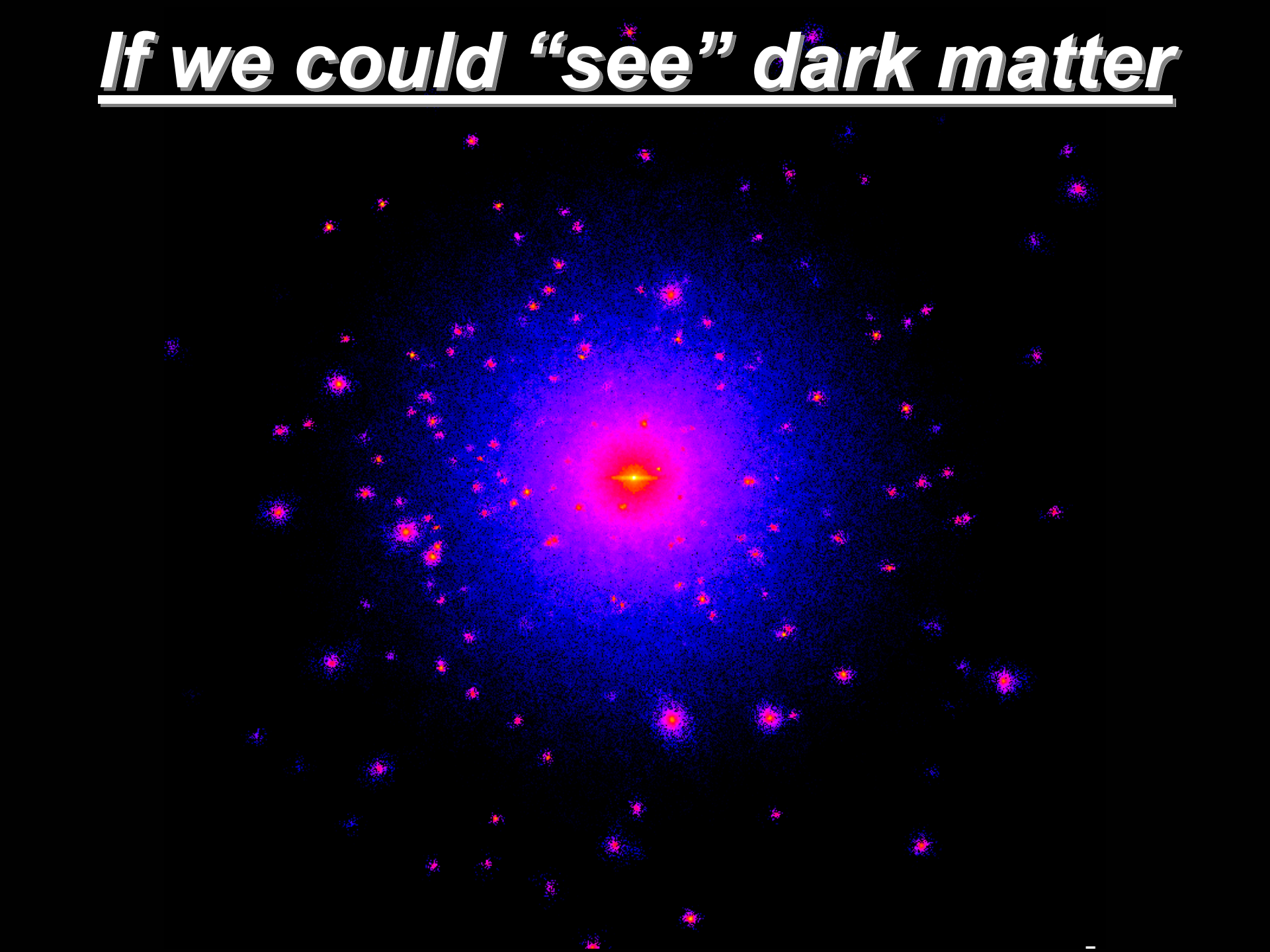

Tony Tyson, Davis

The invisible universe



Dark matter (50 times more than visible matter)

If we could “see” dark matter

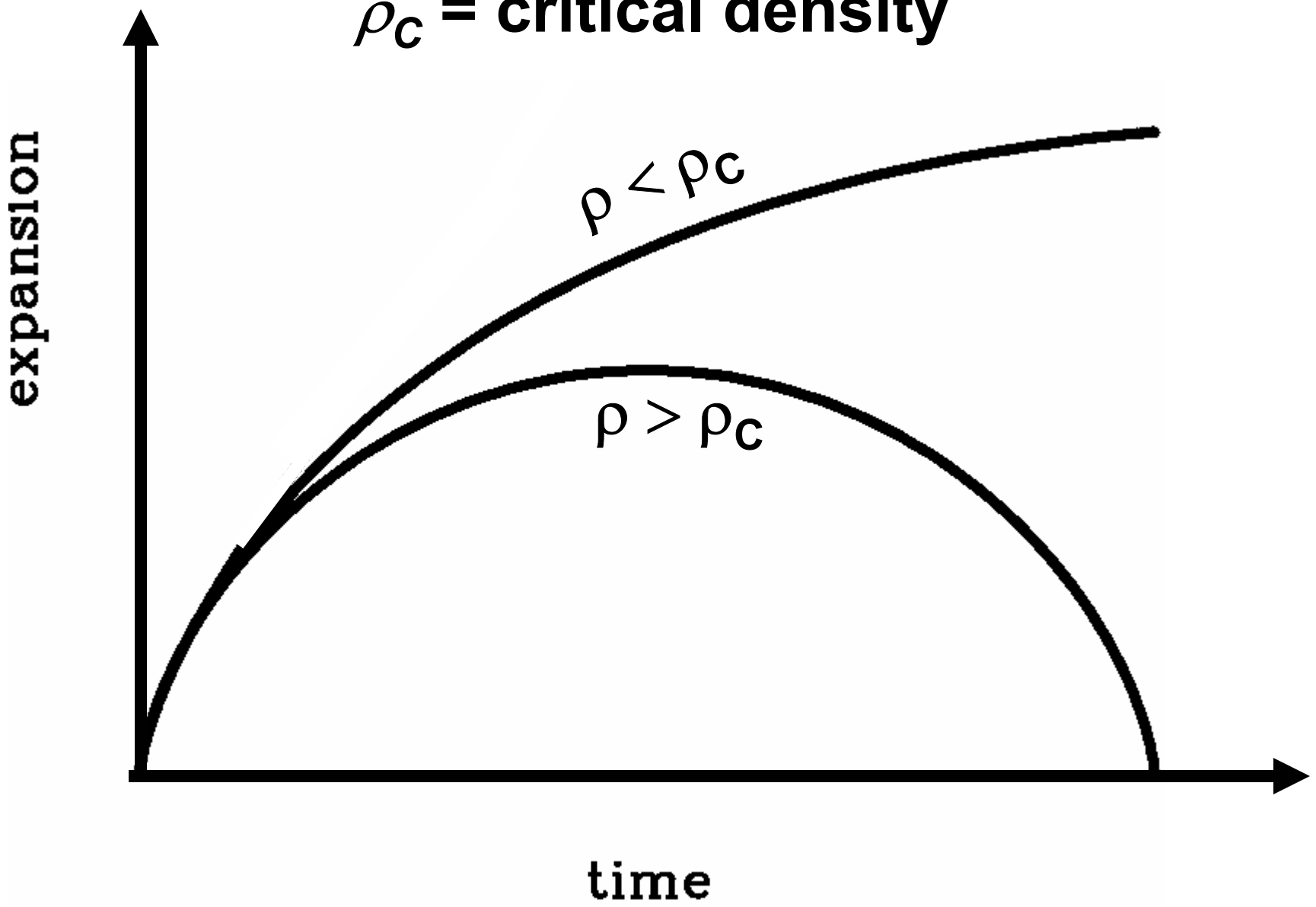


Most of the universe is dark!

It ain’t even normal stuff!

Without Dark Energy

ρ_c = critical density



The cosmic food chain (Ω_i)

- **The critical density:**

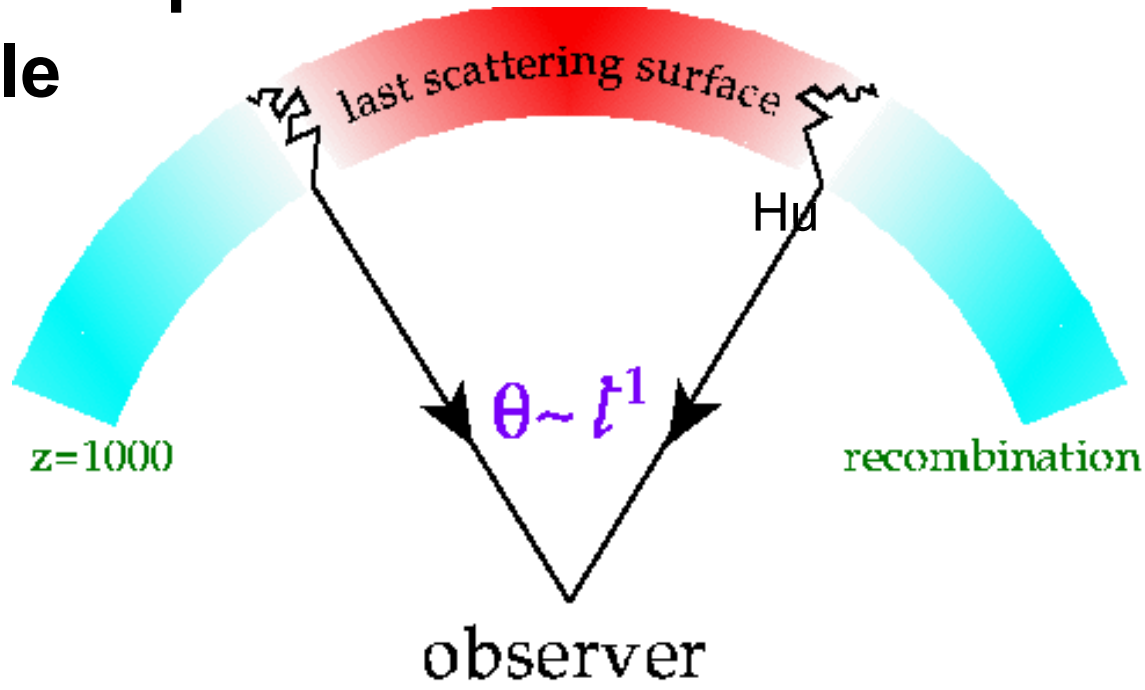
$$\rho_C = \frac{3H_0^2}{8\pi G} \simeq 10^{-30}\ \mathrm{g\ cm^{-3}}$$

- **Fraction of the critical density:**

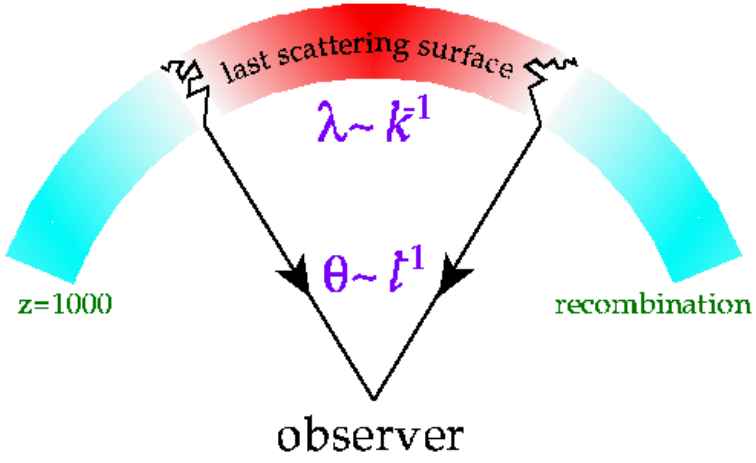
$$\Omega_i = \frac{\rho_i}{\rho_C}$$

Acoustic peaks

- At recombination, baryon–photon fluid undergoes "acoustic oscillations"
- Compressions and rarefactions change T_γ
- Peaks in ΔT_γ correspond to extrema of compressions and rarefactions
- Multipole number corresponds to a physical length scale

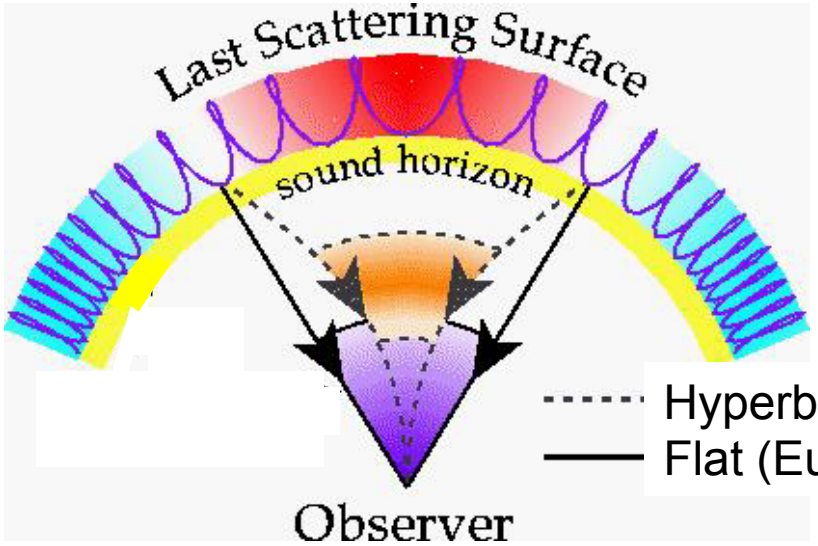


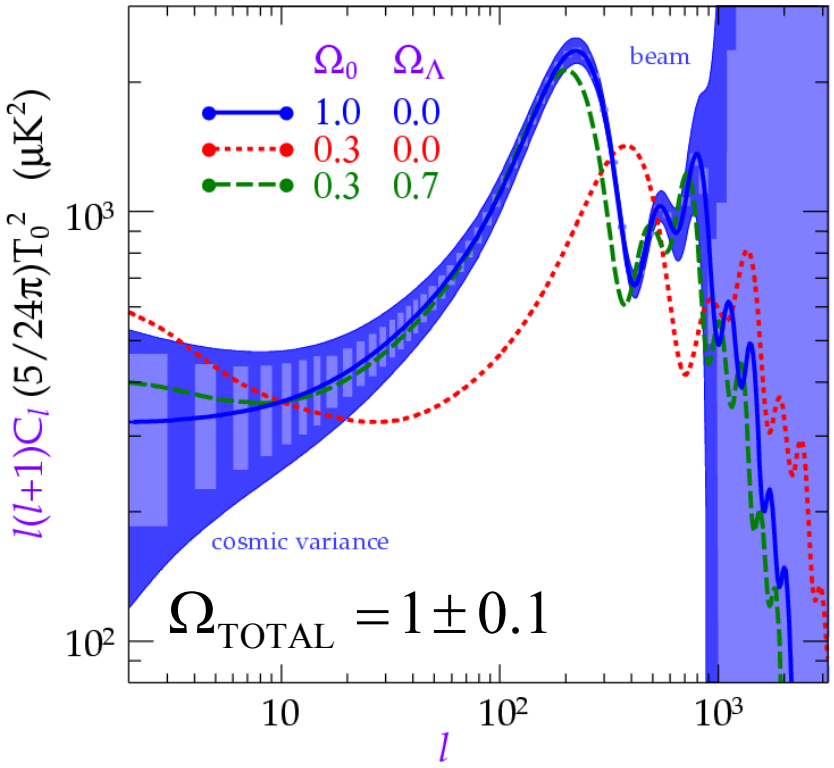
Acoustic peaks



Sound travel distance known

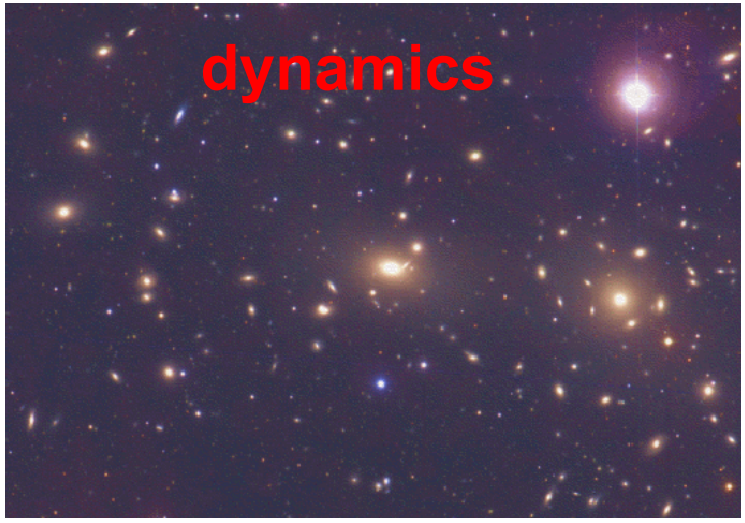
Observed l_{peak} ~ geometry

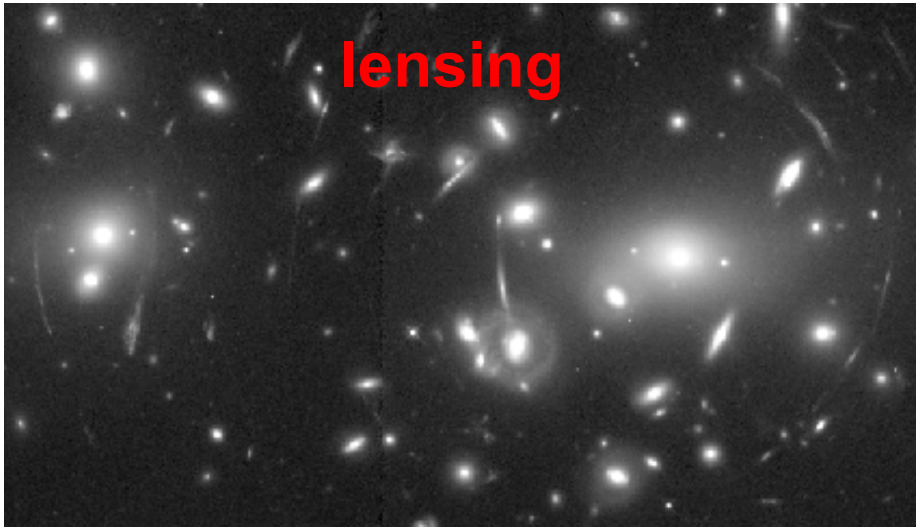


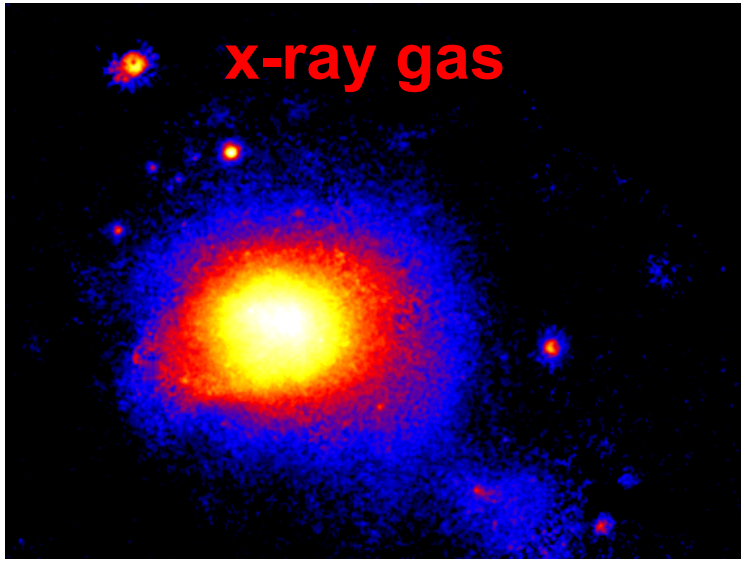


Spherical (closed)

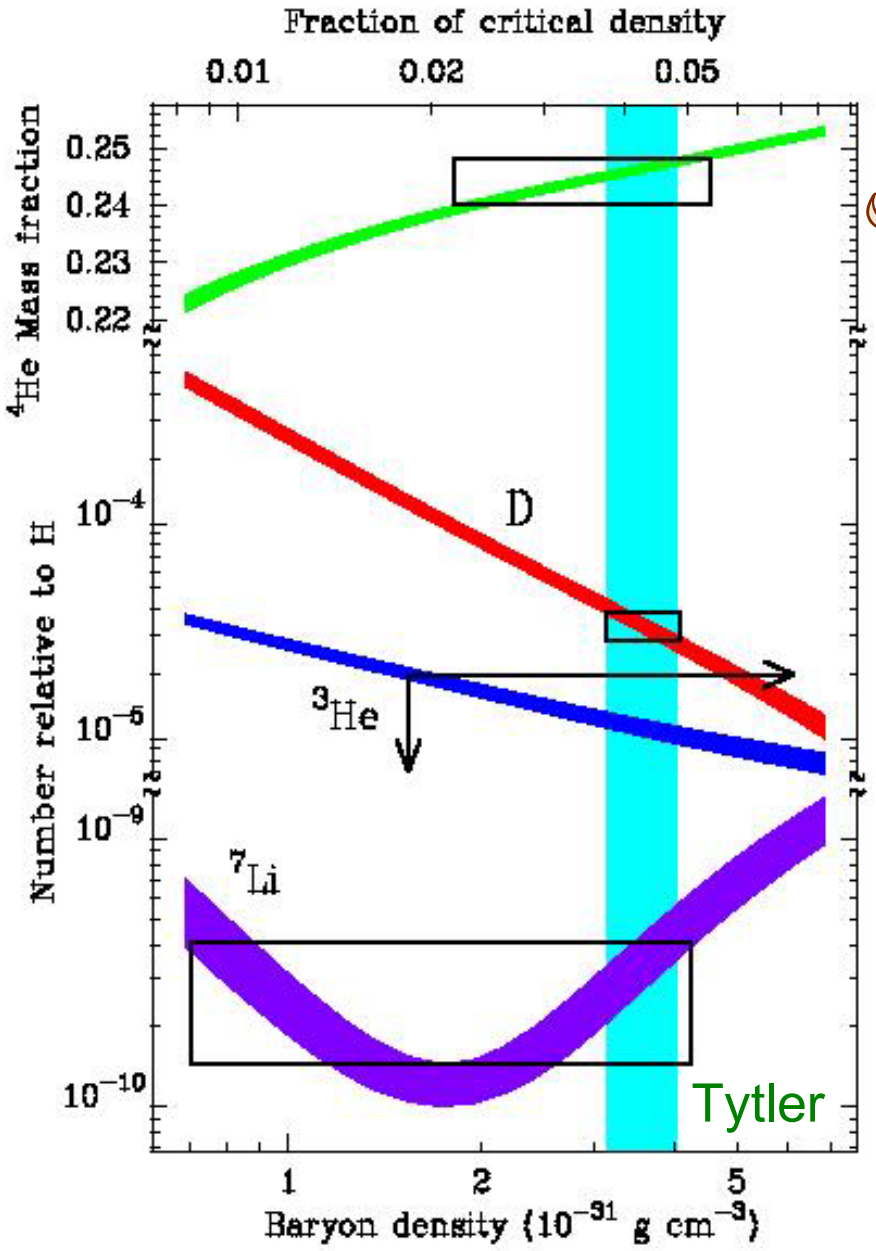
Matter $\Omega_M \sim 0.3$



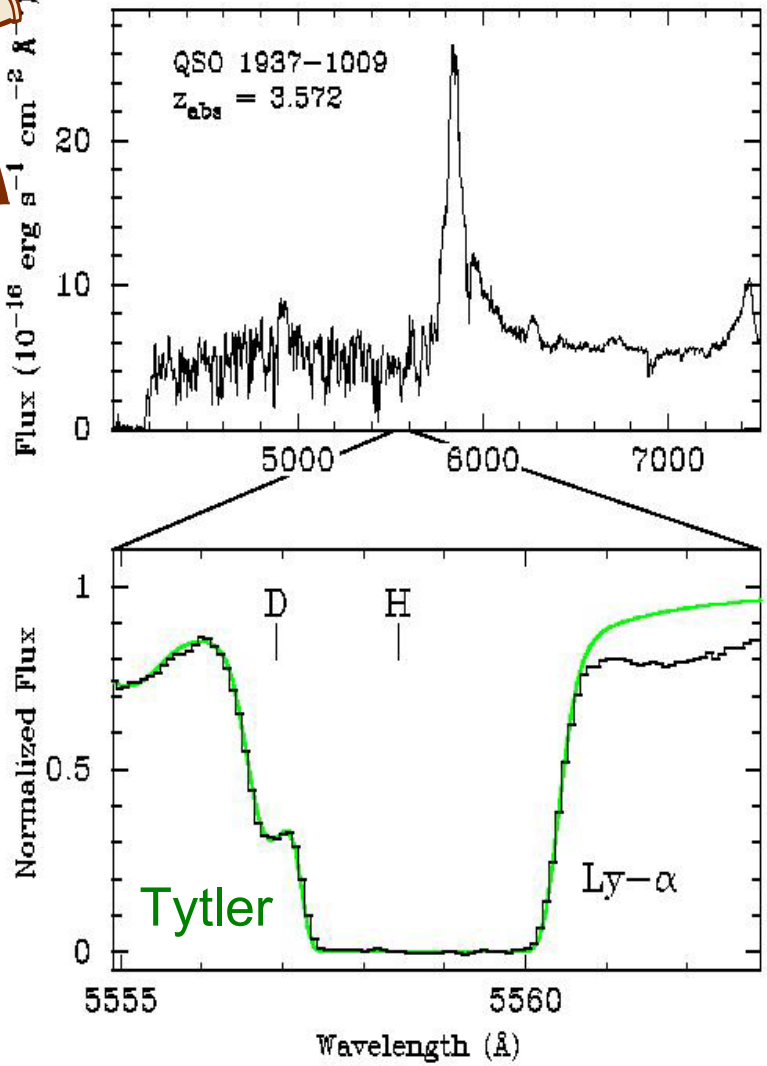




Big Bang Nucleosynthesis



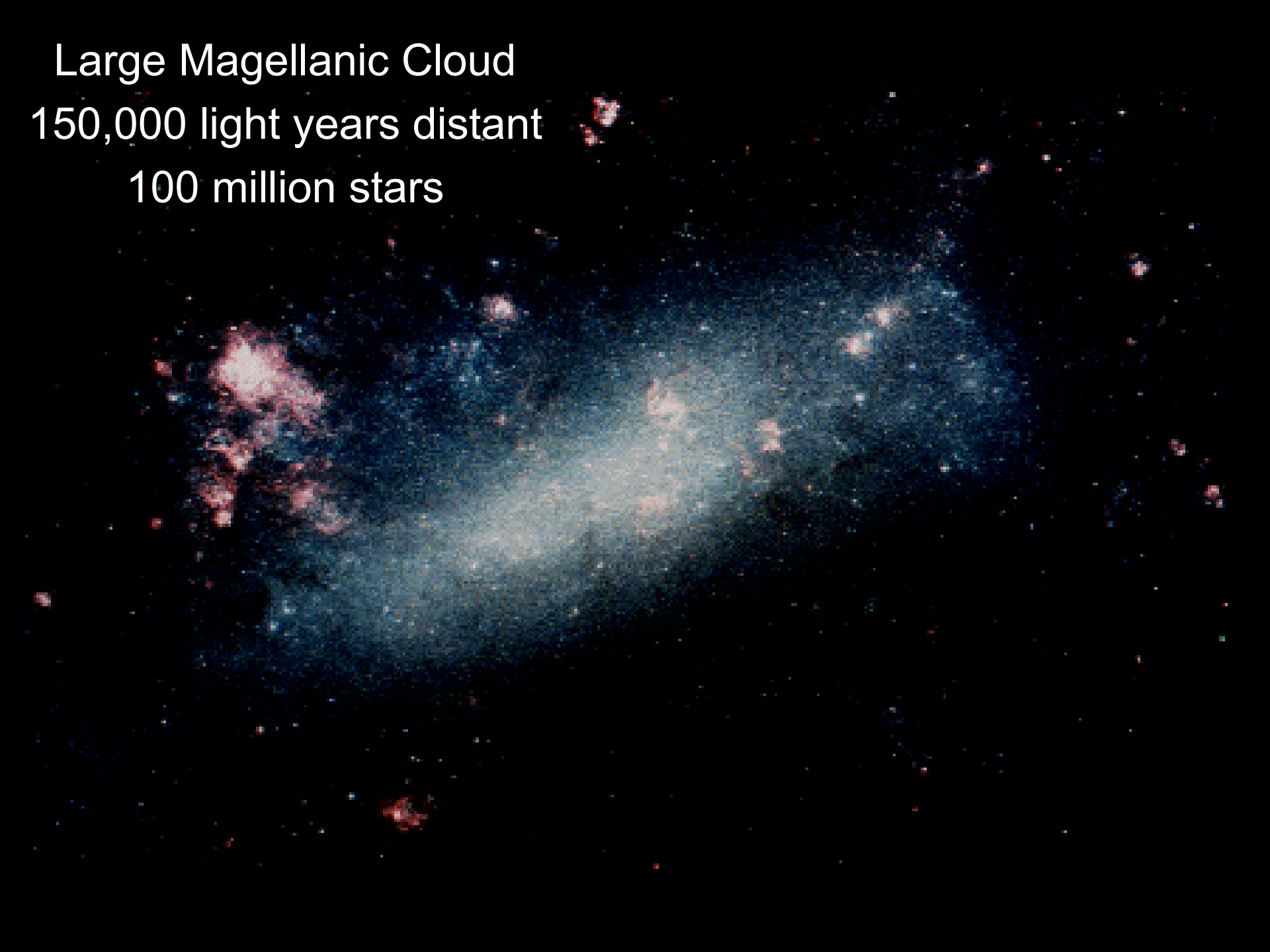
Ly−α

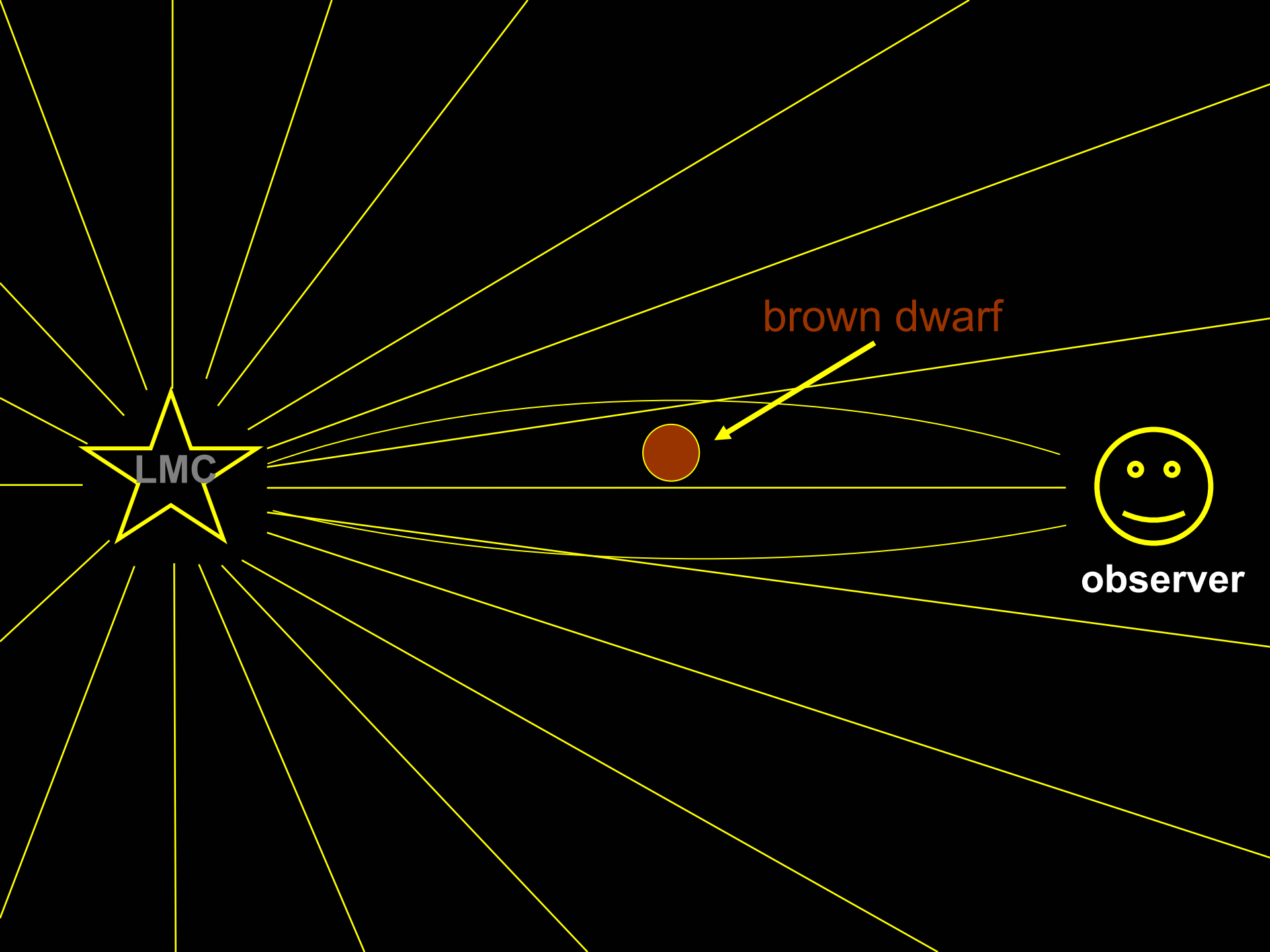


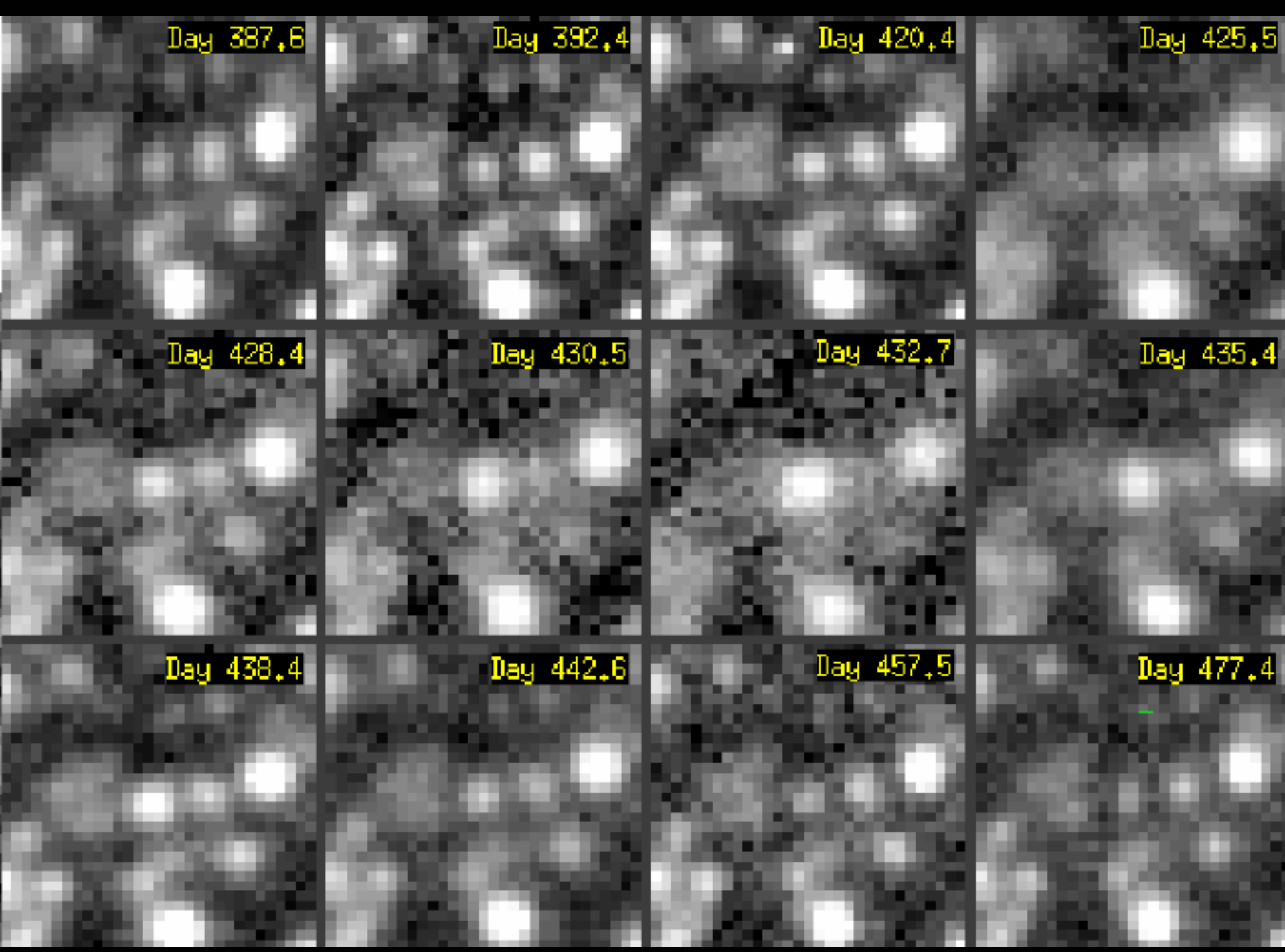
Dark matter?

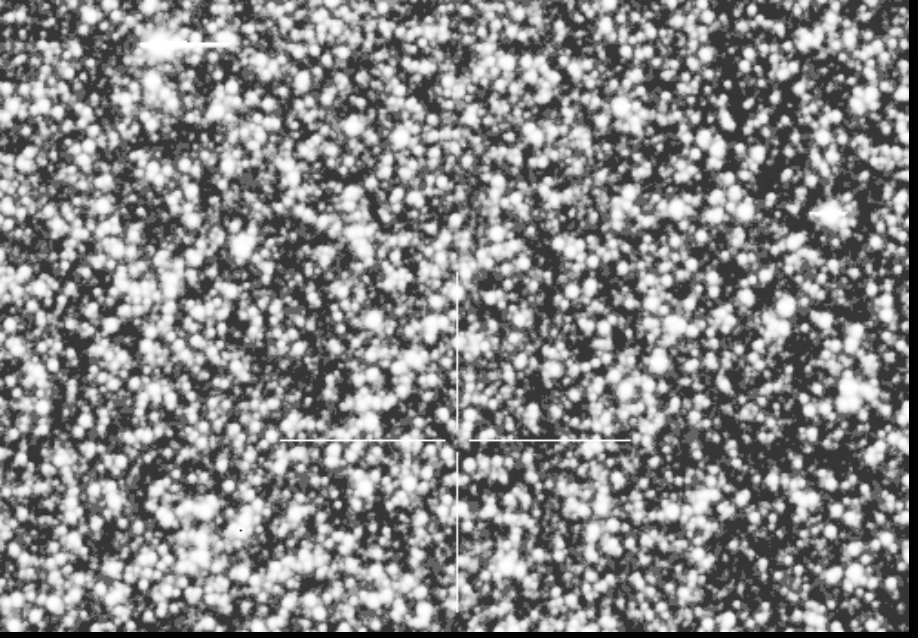
- Modified Newtonian dynamics
- Planets
- Dwarf stars
- Burned-out stars
  - brown
  - red
  - white
- Black holes

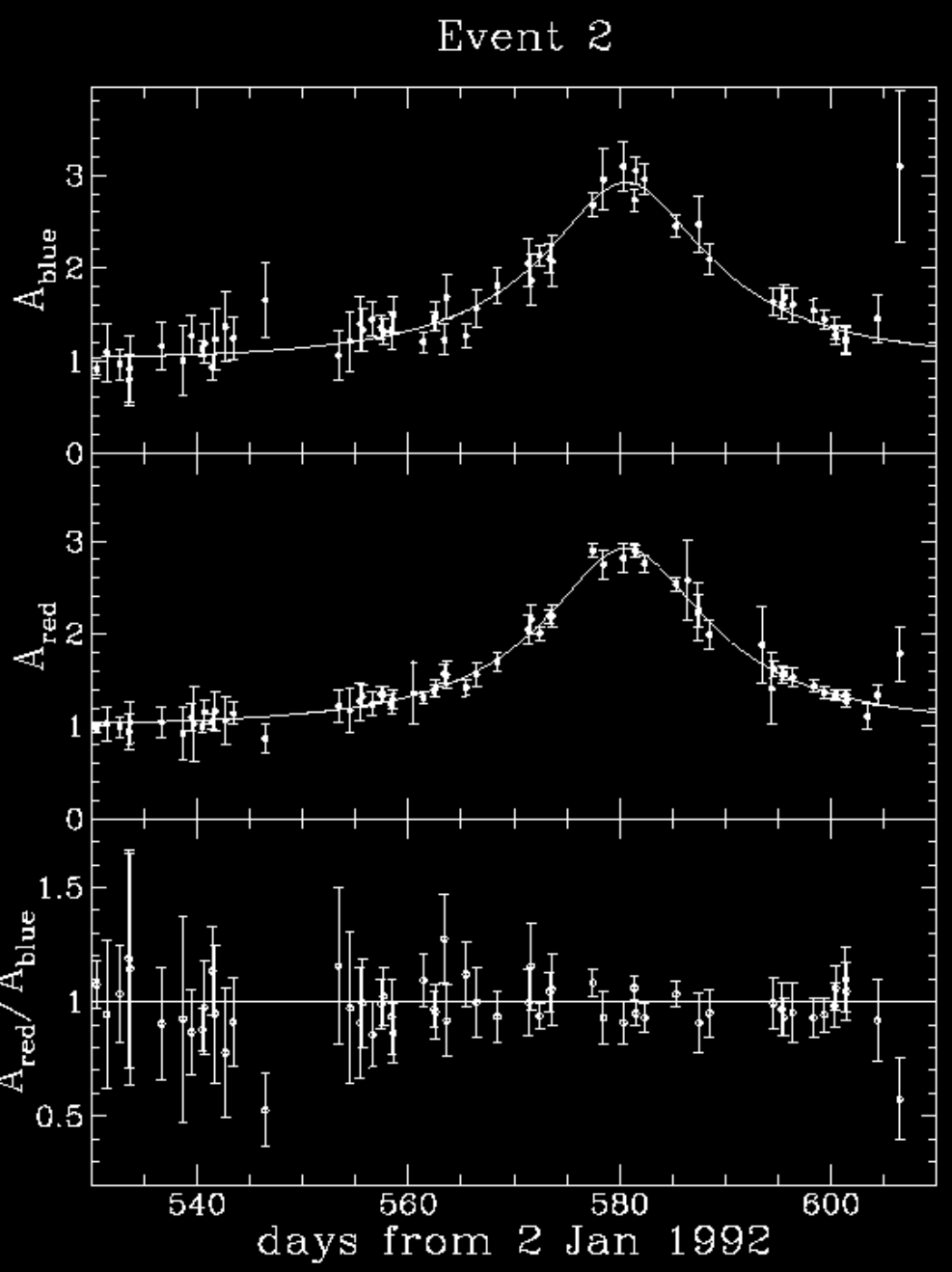
gravitational microlensing


Large Magellanic Cloud
150,000 light years distant
100 million stars


brown dwarf
LMC
observer


Day 387.6
Day 392.4
Day 420.4
Day 425.5
Day 428.4
Day 430.5
Day 432.7
Day 435.4
Day 438.4
Day 442.6
Day 457.5
Day 477.4

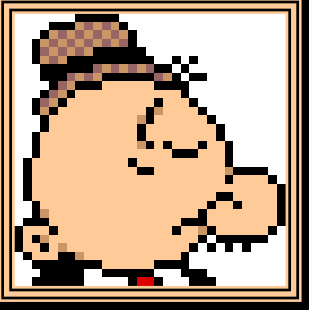



Event 2
A_{blue}
A_{red}
A_{red}/A_{blue}
0
1
2
3
0.5
1.5
540
560
580
600
days from 2 Jan 1992

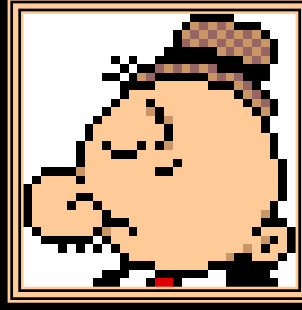
Most of the universe is dark !

- Modified Newtonian dynamics
- Planets
- Size challenged stars

  brown red white
- Black holes
- Fossil remnant of the big bang



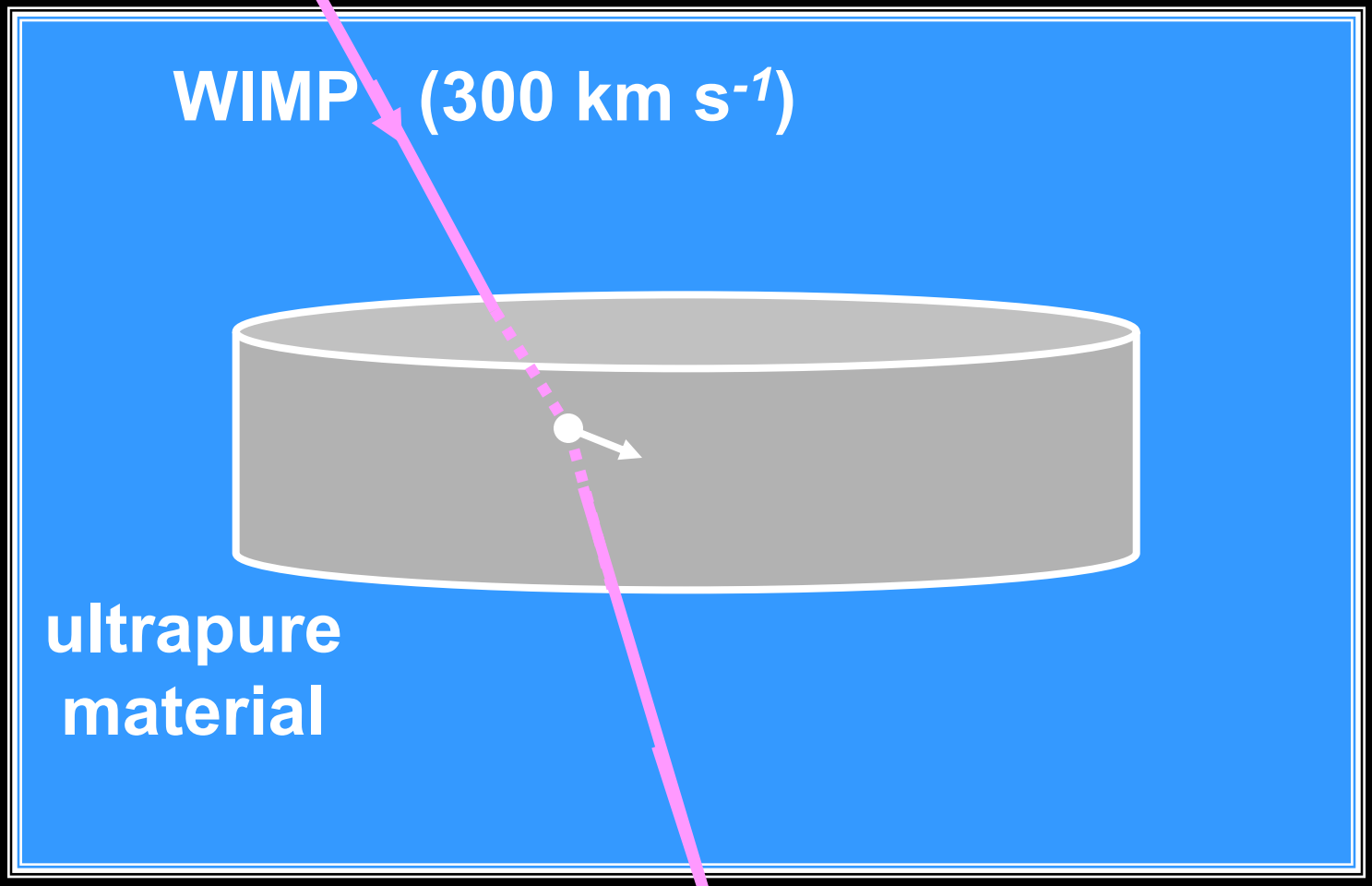
A WIMPY IDEA



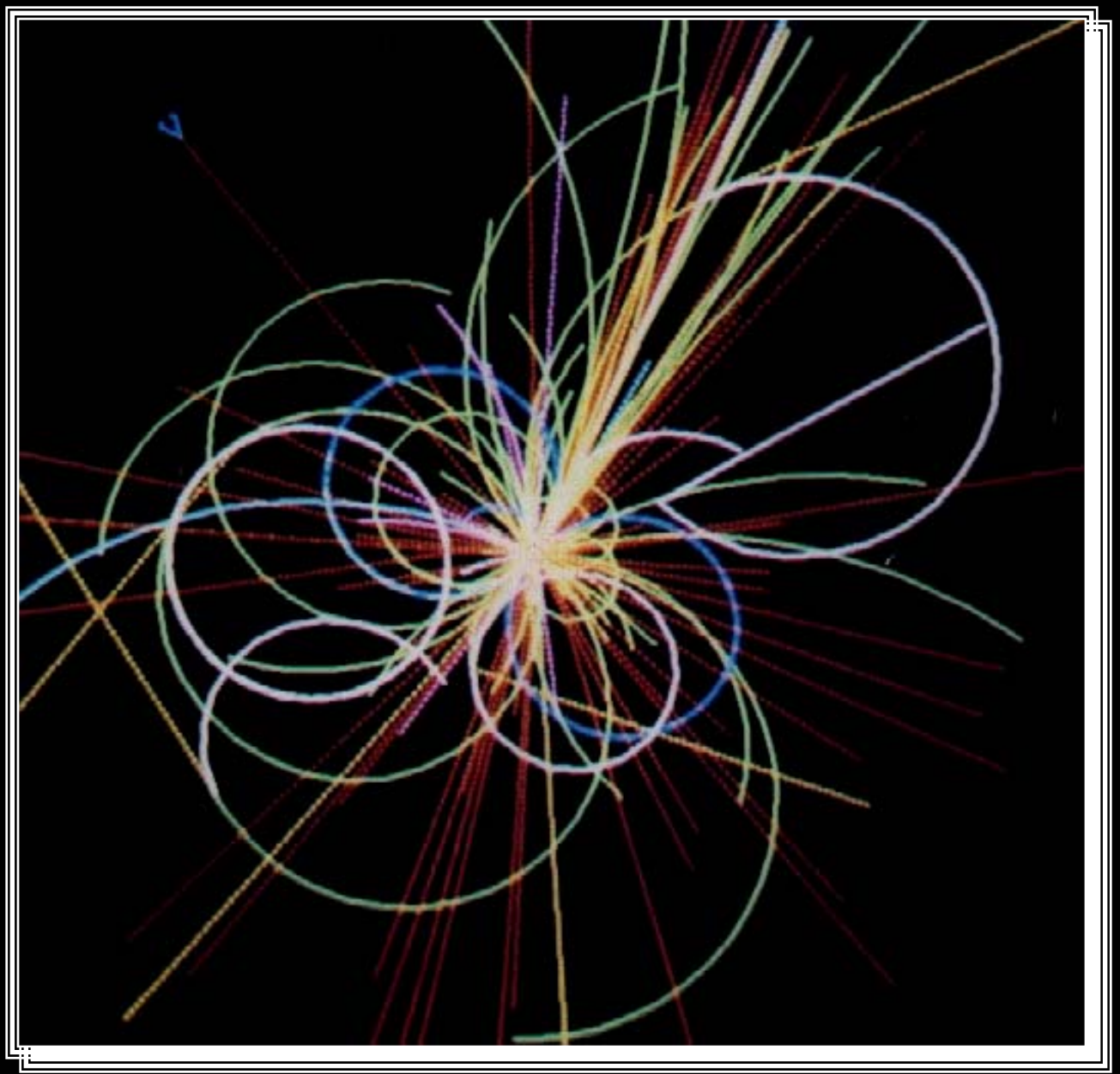
- Most of the universe is *invisible*
- Dominated by the rest mass of an elementary particle
  - present in the primordial soup
  - massive
  - neutral
  - weakly interacting
  - slow
  - stable

WIMP

Direct detection



Make wimps in the laboratory



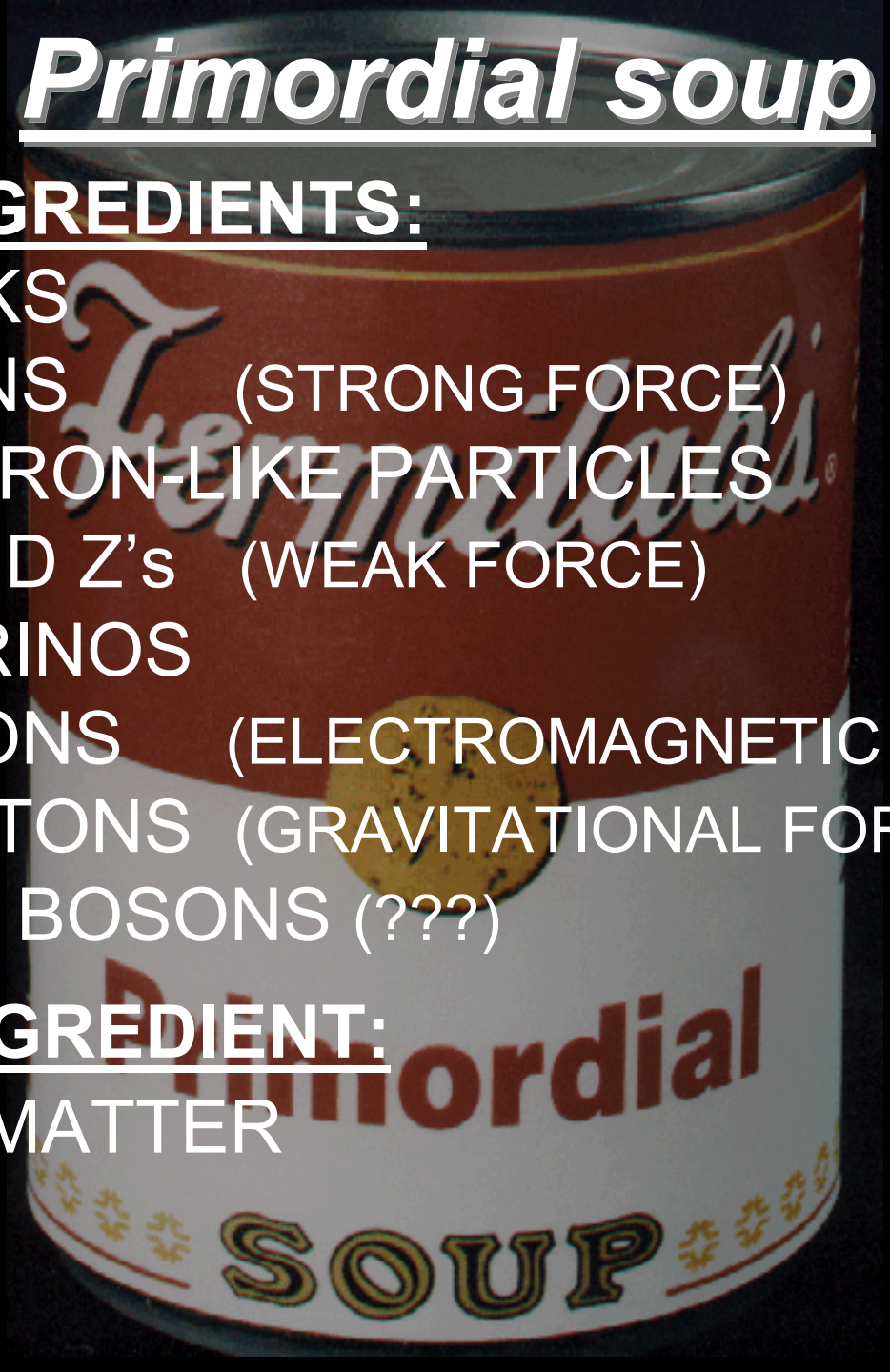
Primordial soup

KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS (???)

SECRET INGREDIENT:

DARK MATTER



Dark energy?

Space and time are related.

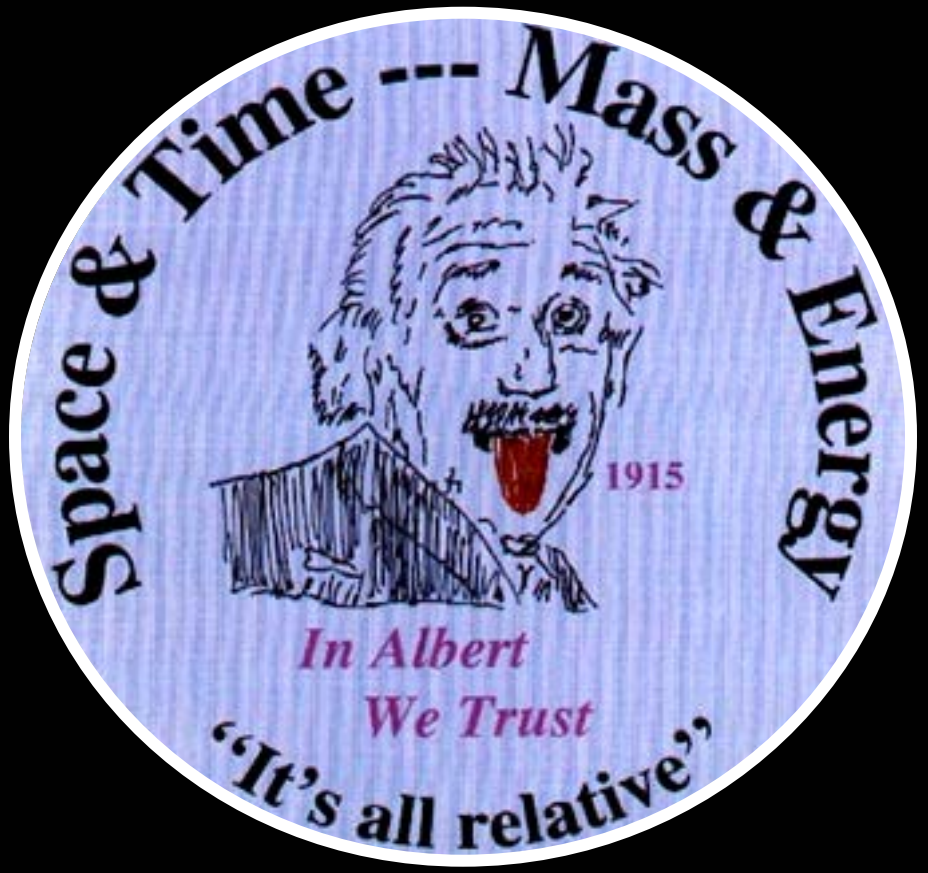
1905

Space is dynamical (curved, warped, bent).

1915

Empty space has a weight.

1917



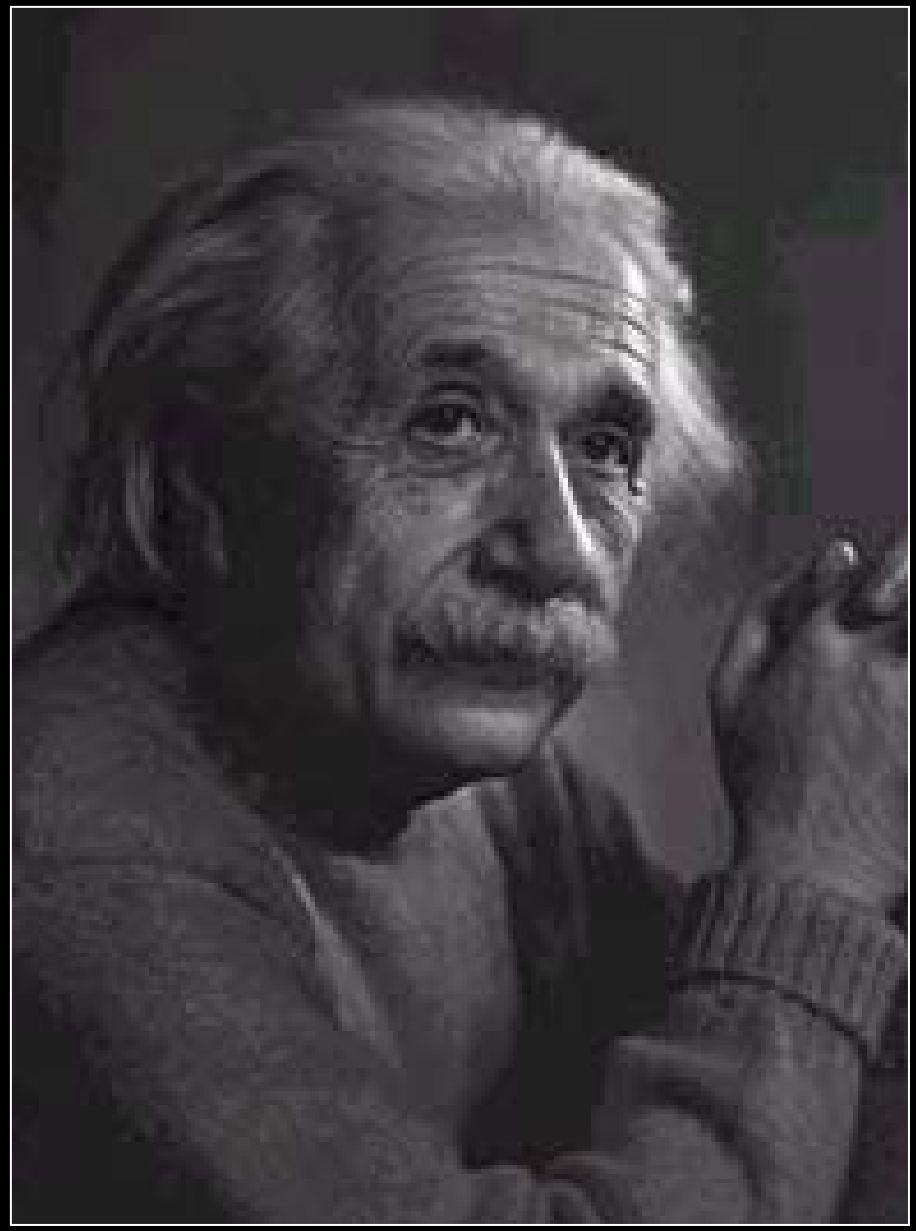
Dark energy

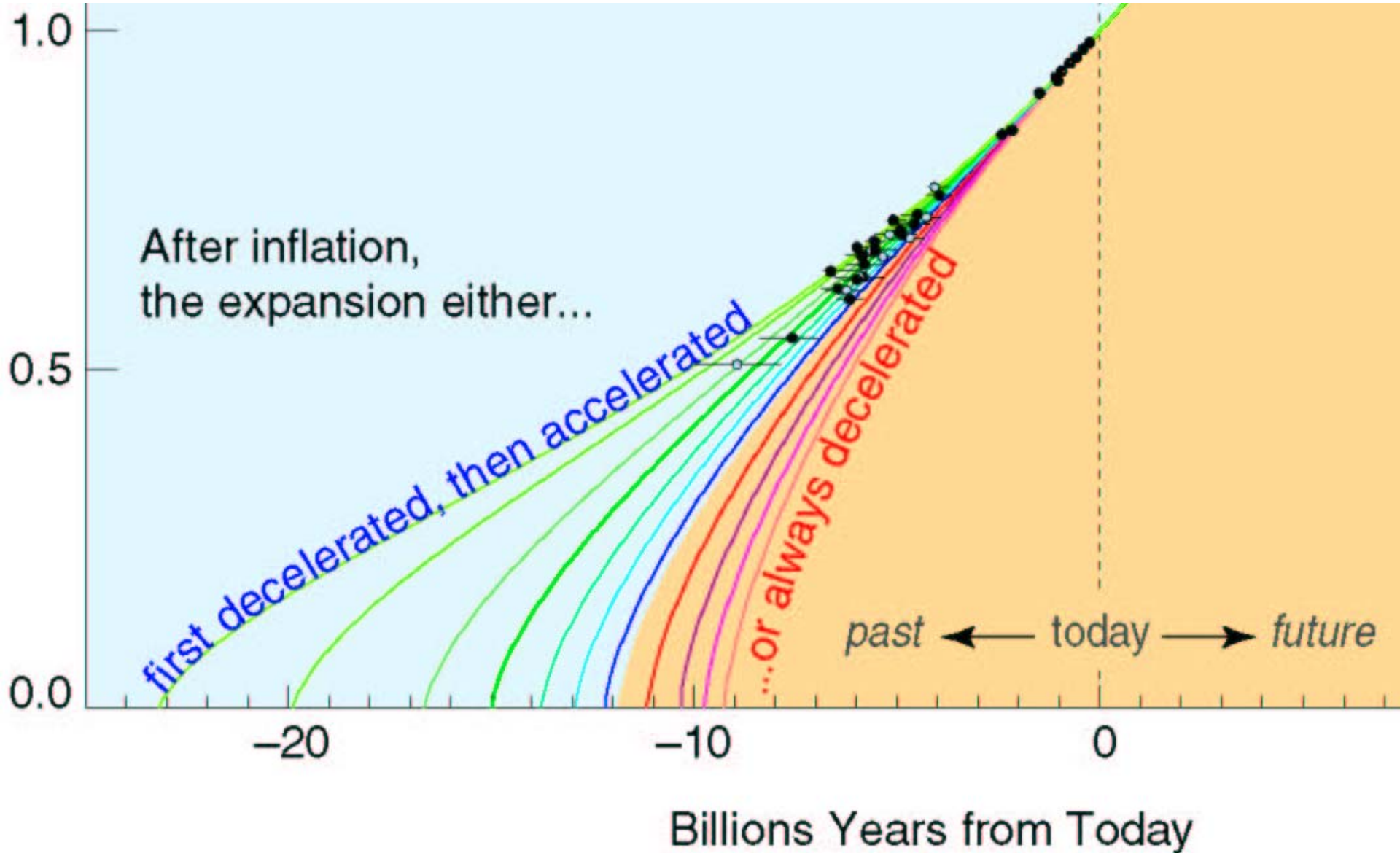
1917 Einstein proposed cosmological constant.

1929 Hubble discovered expansion of the Universe.

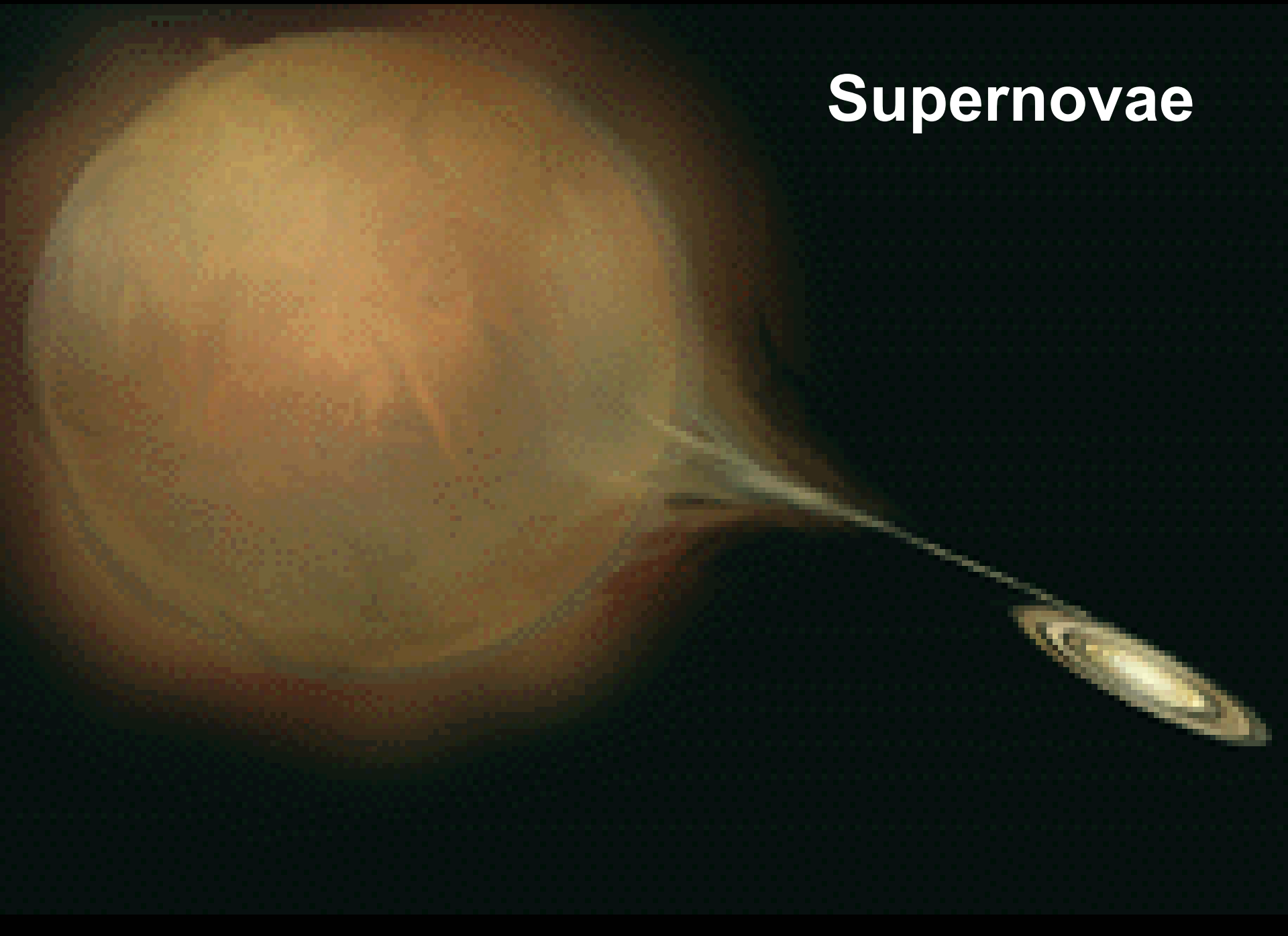
1934 Einstein called it "my biggest blunder."

1998 Astronomers found evidence for it.

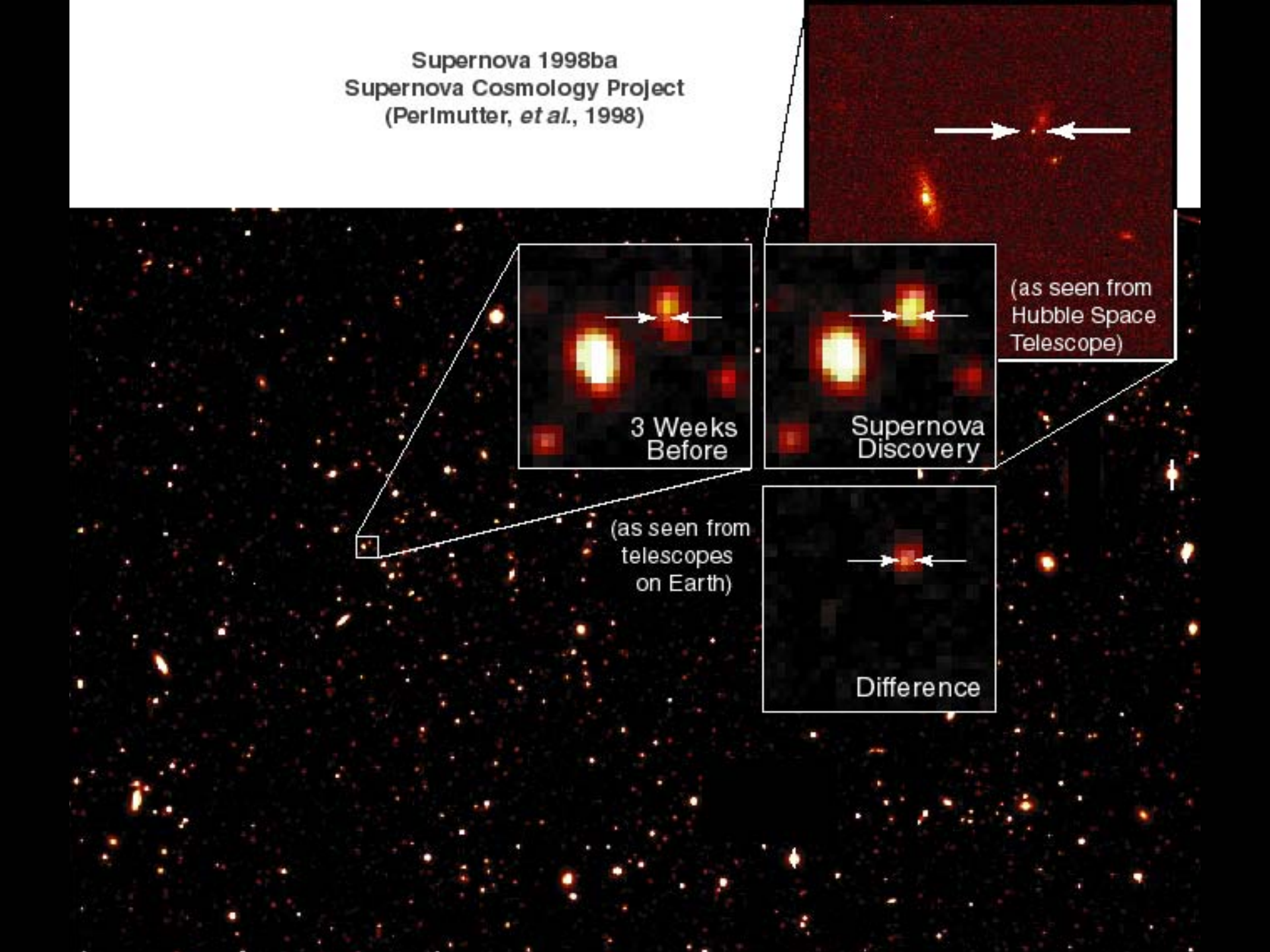



1.0
0.5
0.0
After inflation,
the expansion either...
first decelerated, then accelerated
...or always decelerated
past
today
future
–20
–10
0
Billions Years from Today

Supernovae

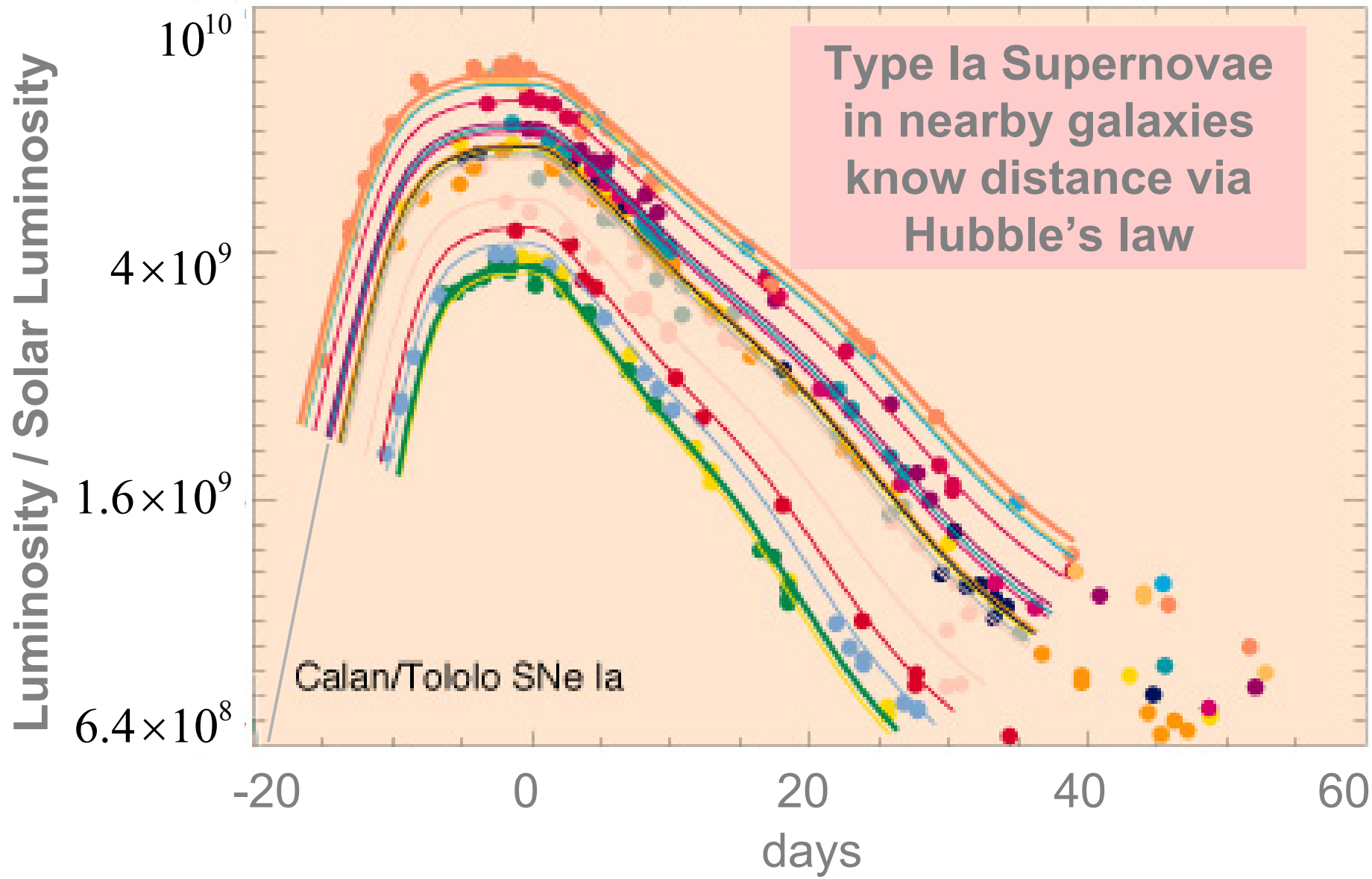


SN 1987A in the LMC

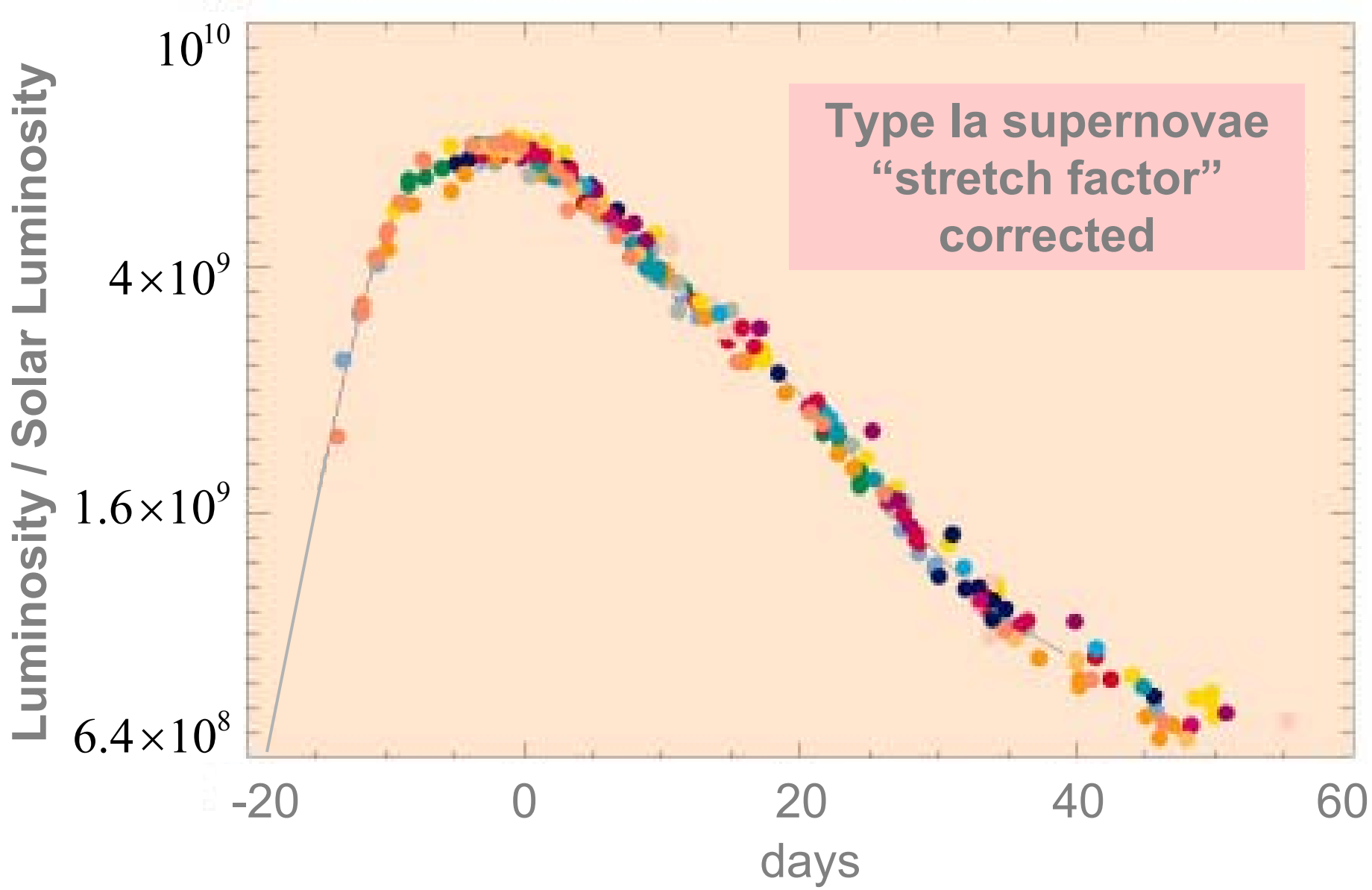

Supernova 1998ba
Supernova Cosmology Project
(Perlmutter, *et al.*, 1998)
(as seen from Hubble Space Telescope)
3 Weeks Before
Supernova Discovery
(as seen from telescopes on Earth)
Difference

Centaurus A

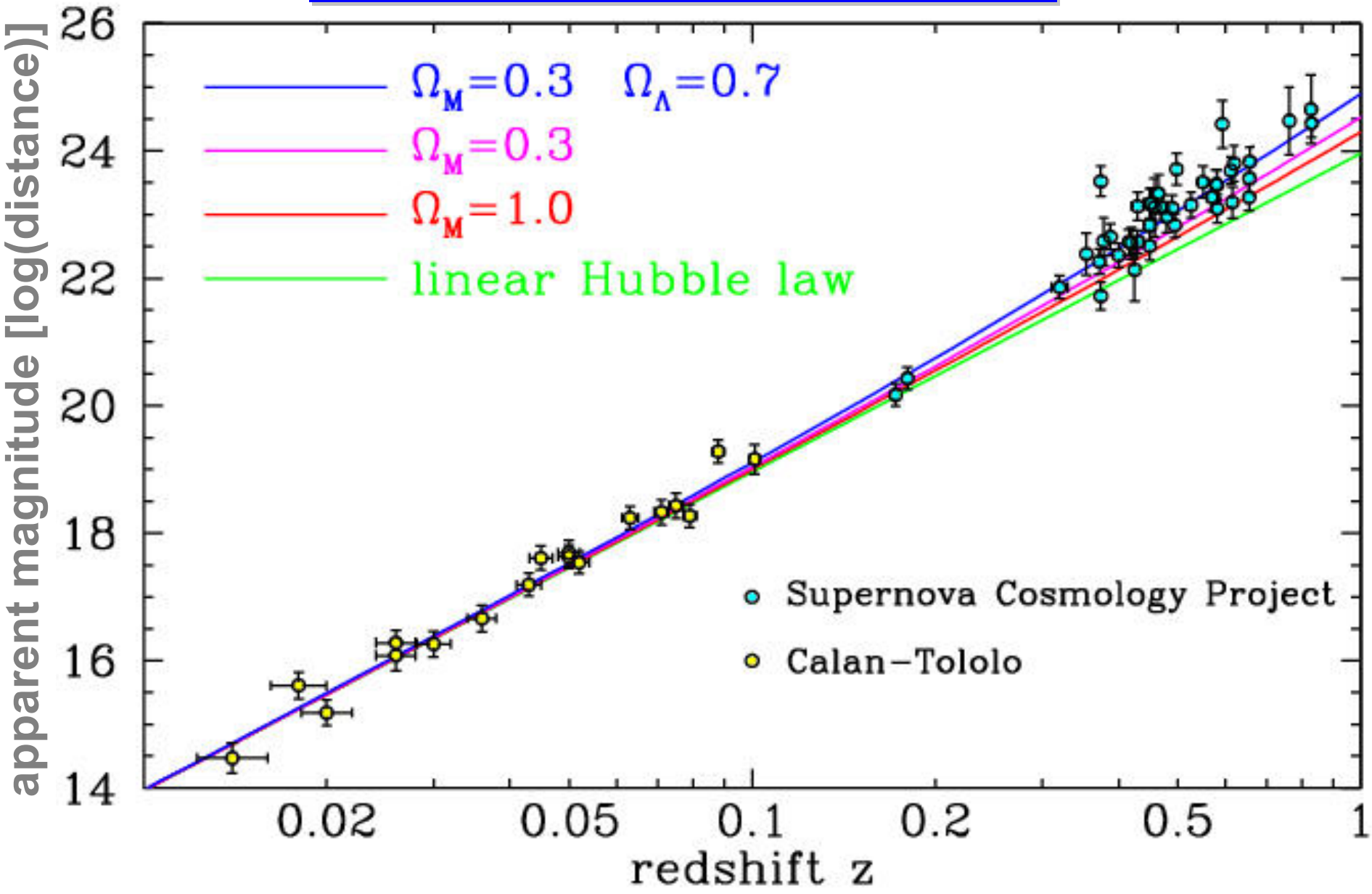
Type Ia supernova are standard candles



Type Ia supernova are standard candles



Type Ia supernova



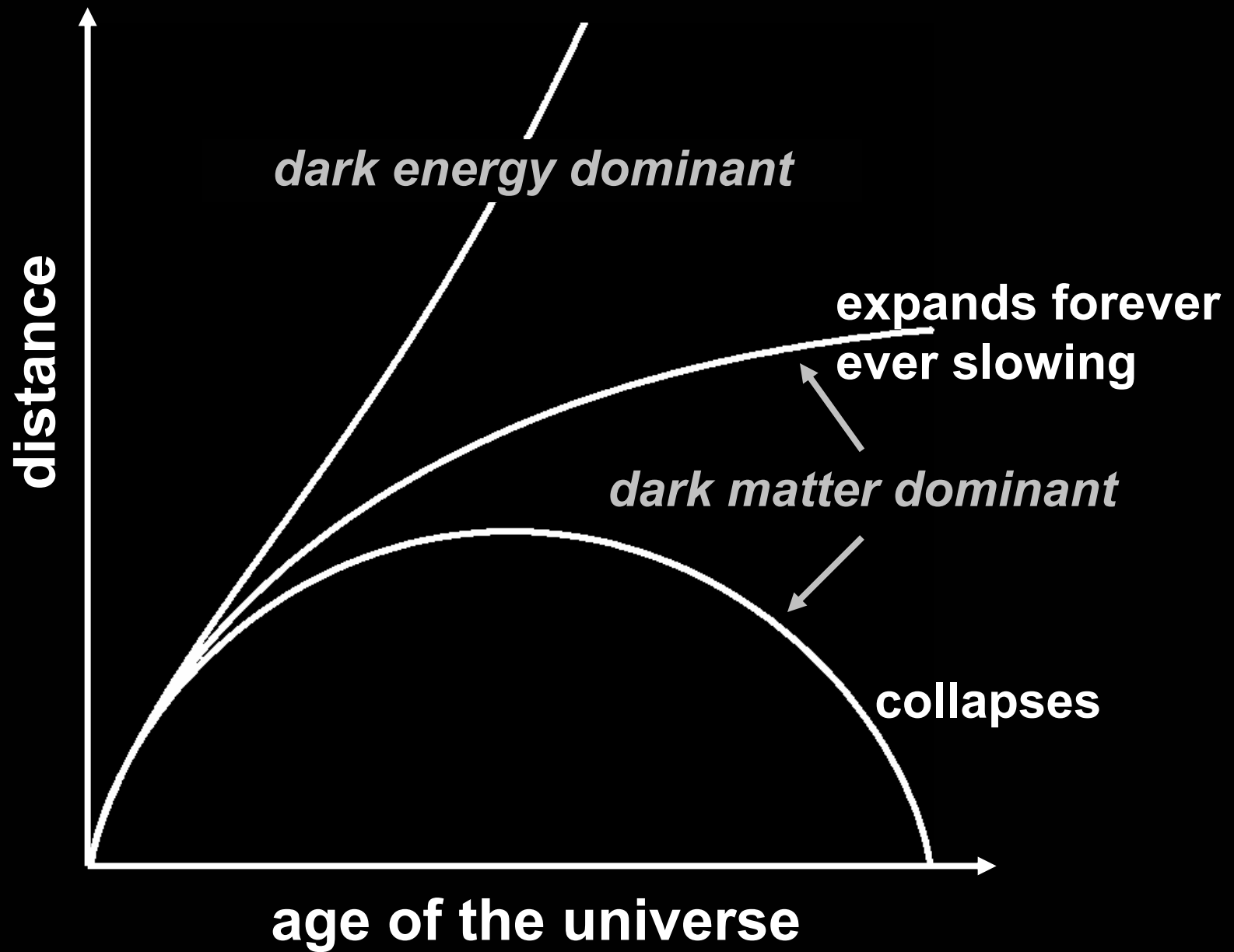
Cosmological constant (Dark energy)

Mass density of space: $10^{-30}\ \mathrm{g\ cm^{-3}}$

The unbearable lightness of nothing!

Cosmo-illogical constant?

Cosmological constant (dark energy)



Vacuum pressure

$E_1 = \rho_V V_1$

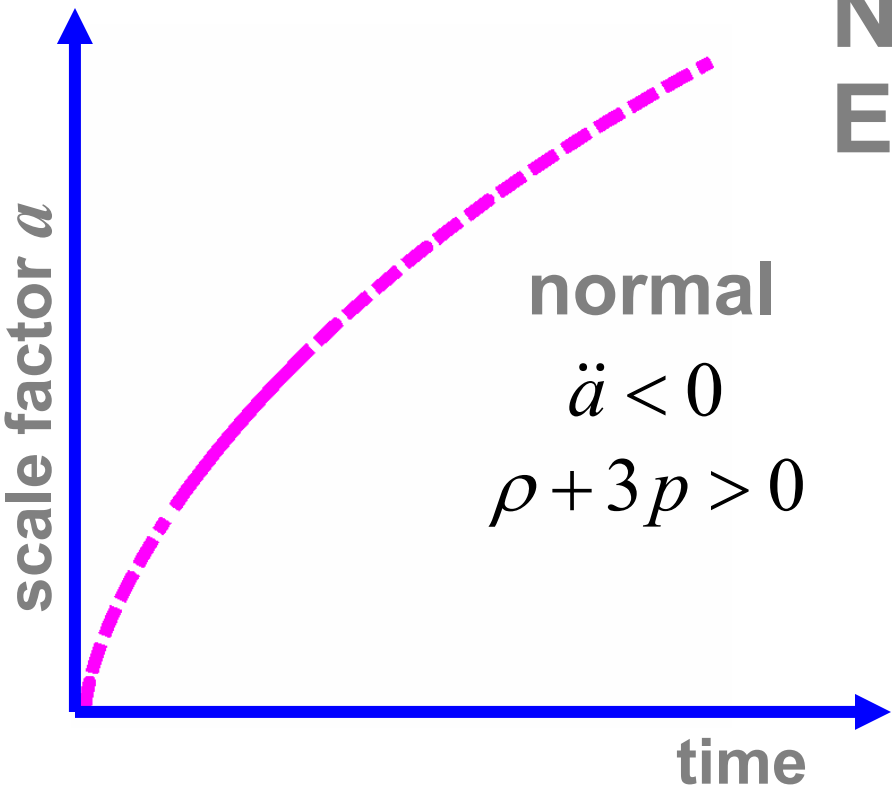
$E_2 = \rho_V V_2$

$E_2 > E_1$

had to pull piston

"negative pressure"

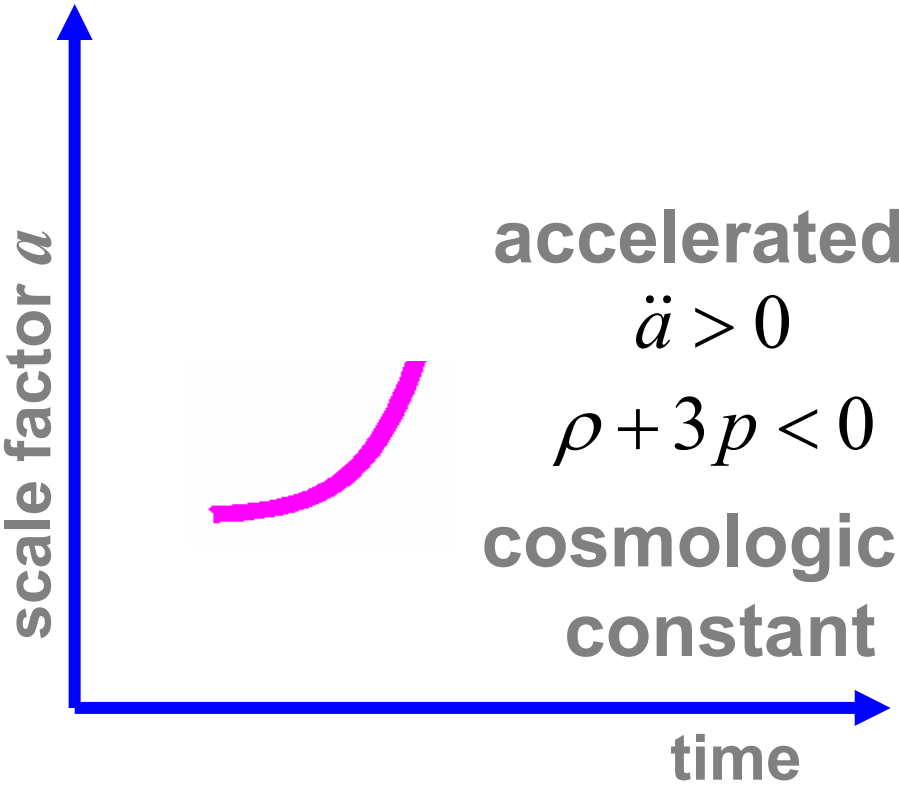
Newton
Einstein $\ddot{a} \propto -G\left(\rho + 3p\right)$



normal

$\ddot{a} < 0$

$\rho + 3p > 0$



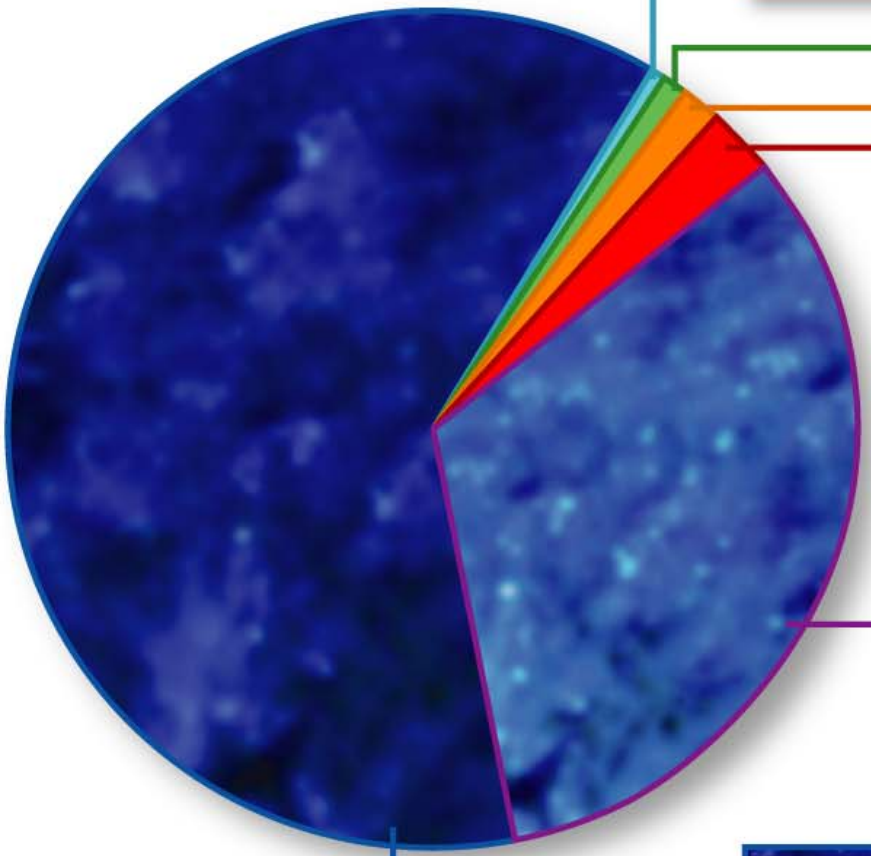
accelerated

$\ddot{a} > 0$

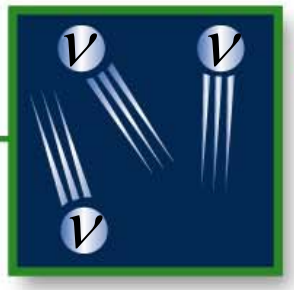
$\rho + 3p < 0$

cosmological constant

Cosmic Pie

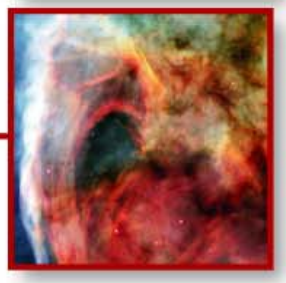


Chemical Elements:
(other than H & He) 0.03%

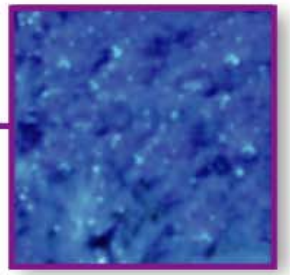


Neutrinos:
0.47%

Stars:
0.5%



Free H
& He:
4%



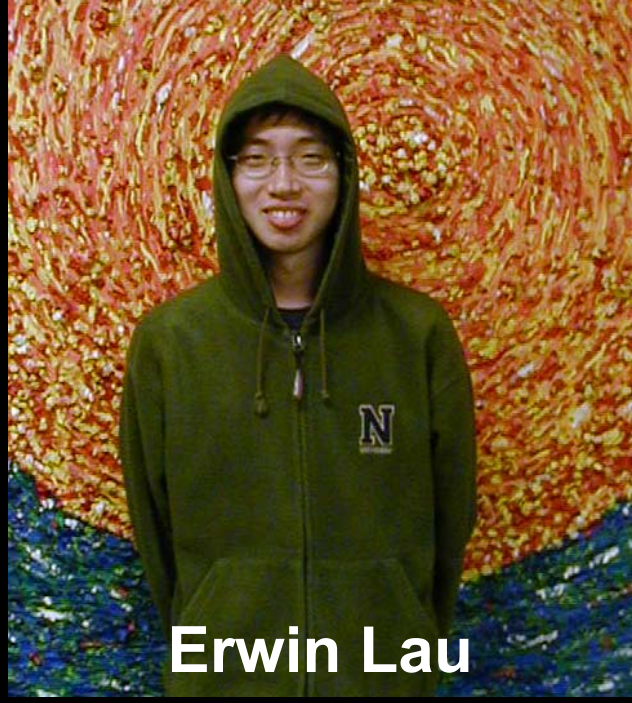
Dark Matter:
25%

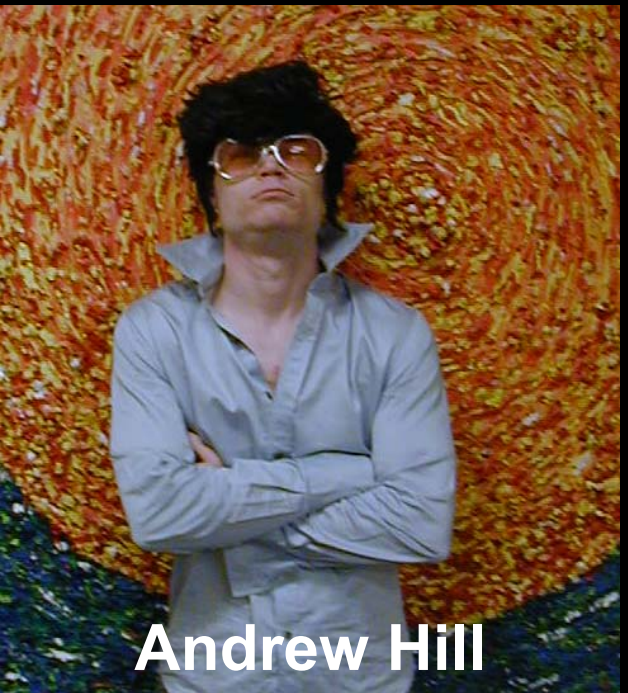
Dark Energy:
70%

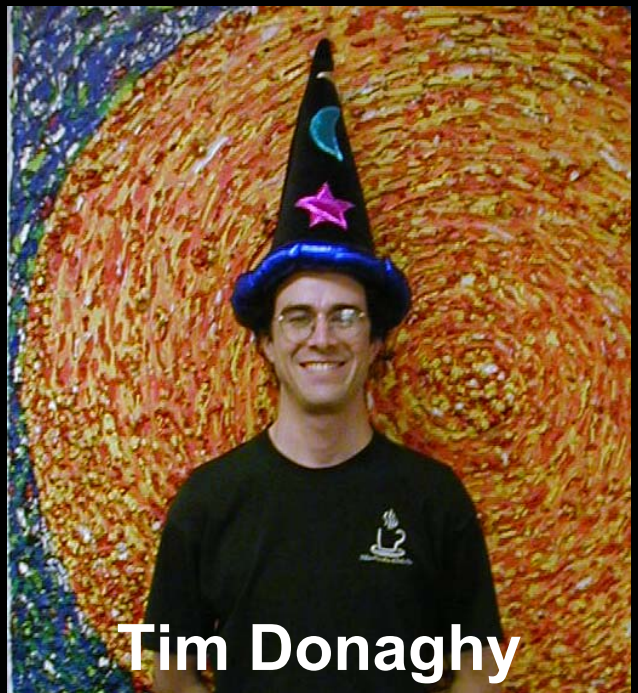
Nothing matters!

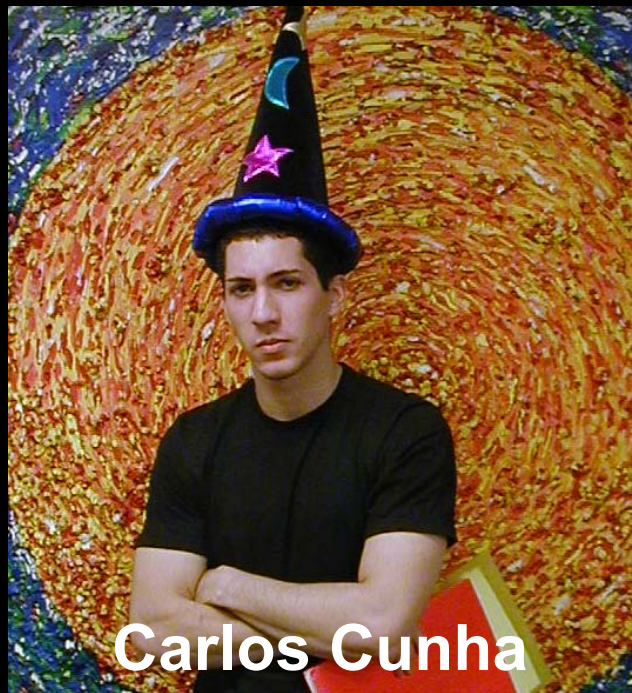

Felipe Marin


Alberto Vallinotto


Erwin Lau


Andrew Hill


Tim Donaghy


Carlos Cunha